ICPPA - Moscow, Oct. 6-9, 2015

INFN Astroparticle Projects in collaboration with Russia

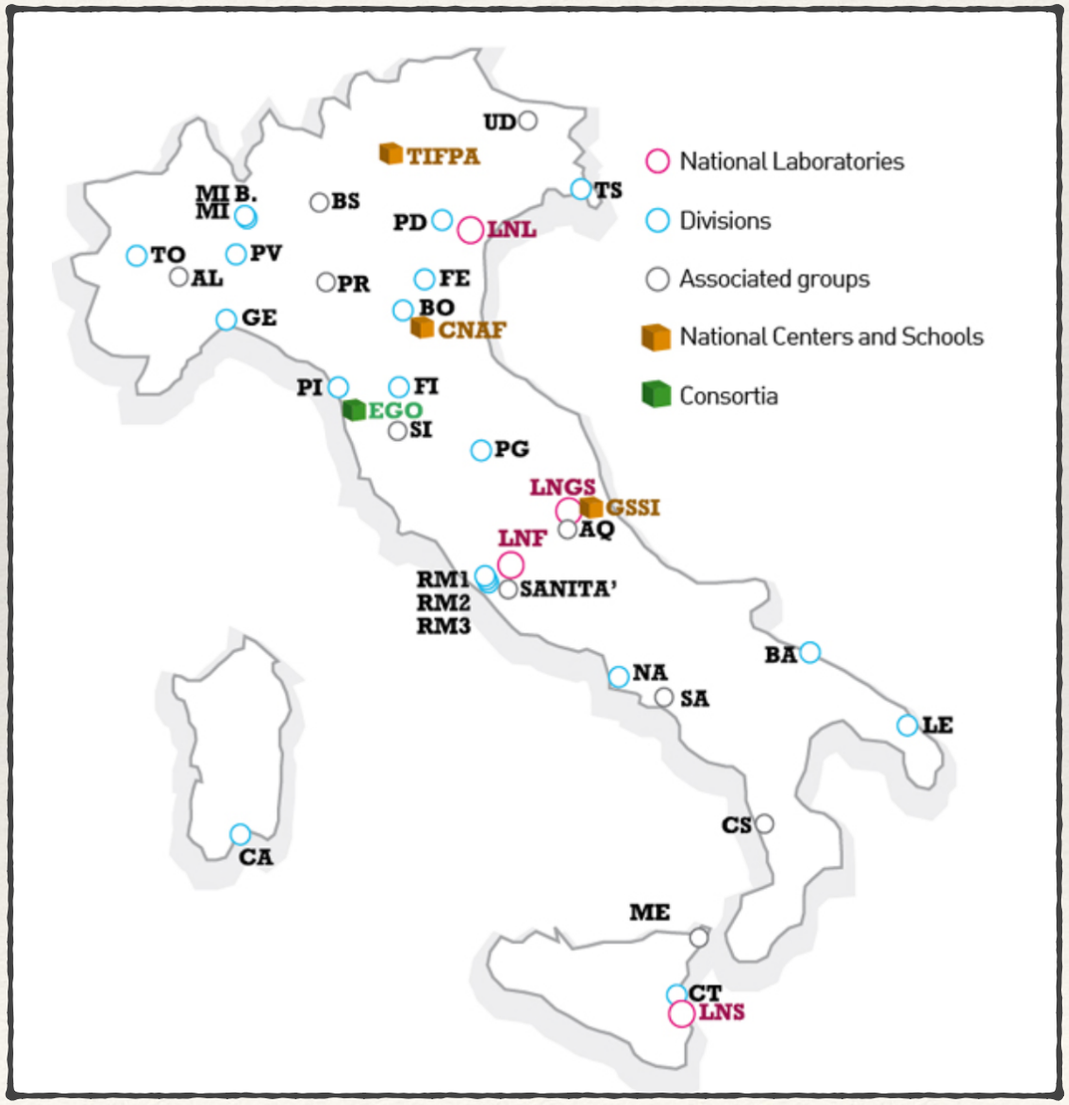
Prof. Marco Pallavicini

Chair of INFN Astroparticle and Fundamental Physics Commission II

Università di Genova & INFN

The INFN

- The **National Institute for Nuclear Physics** (INFN) is the Italian research agency dedicated to the study of the fundamental constituents of matter
  - Managed under supervision of Ministry of Education (MIUR)
  - It conducts theoretical and experimental research in the fields of subnuclear, nuclear and astro-particle physics.
  - Funded: 1951
  - **4 National Laboratories**
    - Frascati, Gran Sasso, Legnaro, Catania
  - **20 Directors** for 20 regional divisions
  - 6 Foundations or External Structures



INFN SCIENTIFIC ORGANIZATION

- INFN [3670 Full Time Equivalent (FTE), research staff + university associates]
  - **Five "Commissioni Scientifiche Nazionali"**

• CSN1 : Particle Physics with Accelerators	19.8 M€	796 FTE	**2015**
• **CSN2: Astroparticle and Fundamental Physics**	**12.3+9 M€**	**726 FTE**	
• CSN3: Nuclear Physics	9.2 M€	494 FTE	
• CSN4: Theory	2.7 M€	991 FTE	
• CSN5: Technology	5.3 M€	663 FTE	

- CSN2: **Astroparticle and Fundamental Physics**
  - 4 main areas of scientific activity (new structure, 2015)
    - 1) Neutrino Physics
    - 2) Radiation from the Universe
    - 3) The Dark Universe
    - 4) Gravitational Waves, Gravity and Quantum Physics

CSN2: Astroparticle and Fundamental Physics

- Four areas of research….

Neutrino Physics

Radiation from the Universe

Gravitational waves, Gravity and Quantum Physics

The Dark Universe

CSN2: Astroparticle and Fundamental Physics

- Four areas of research… with **solid long standing collaboration** with **Russian** institutions and Dubna International Laboratory

BOREXino
GERDA
ICARUS
LUCIFER
LUMINEU
JUNO
LVD
SOX
T2K

Neutrino Physics

Radiation from the Universe

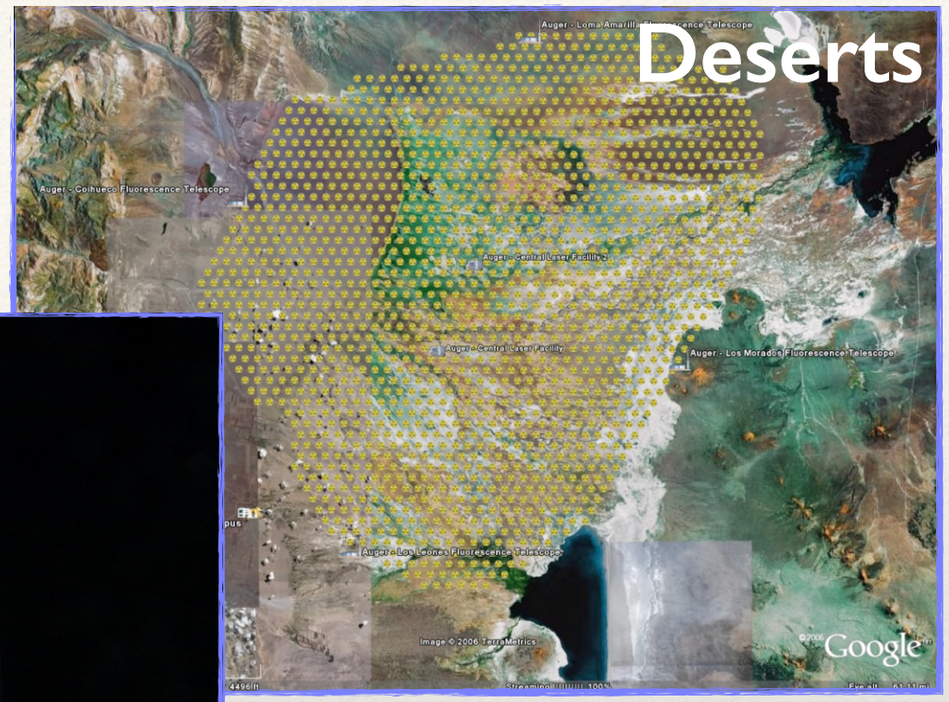
PAMELA
GAMMA-400

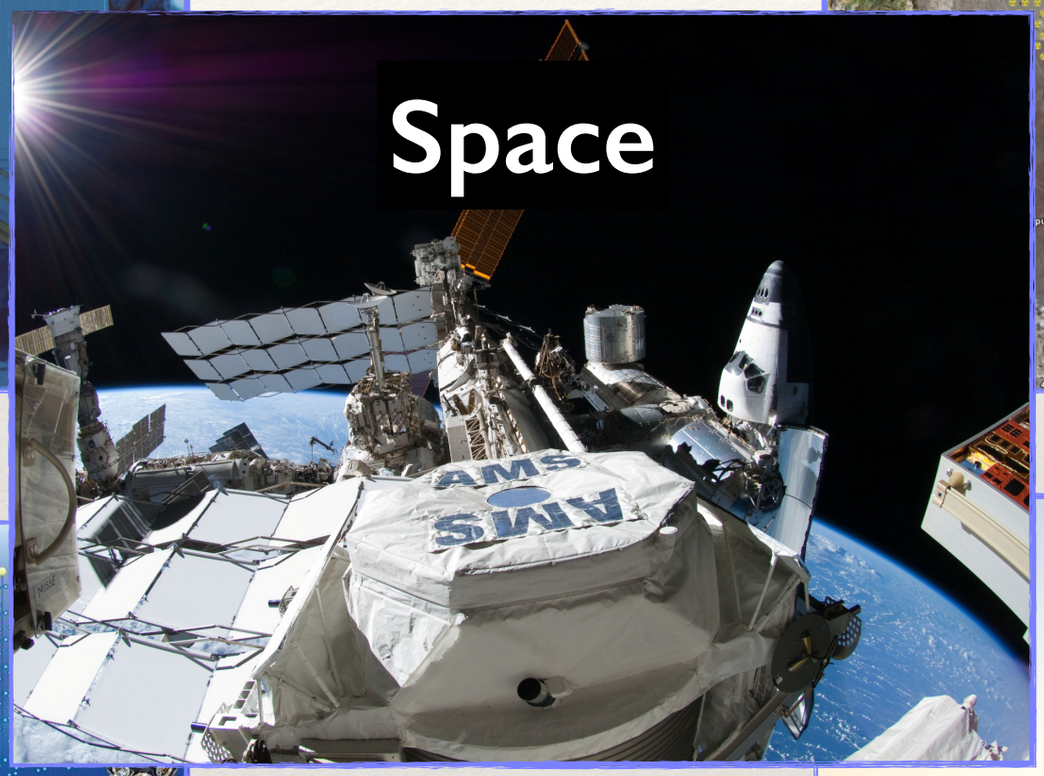
Gravitational waves, Gravity and Quantum Physics

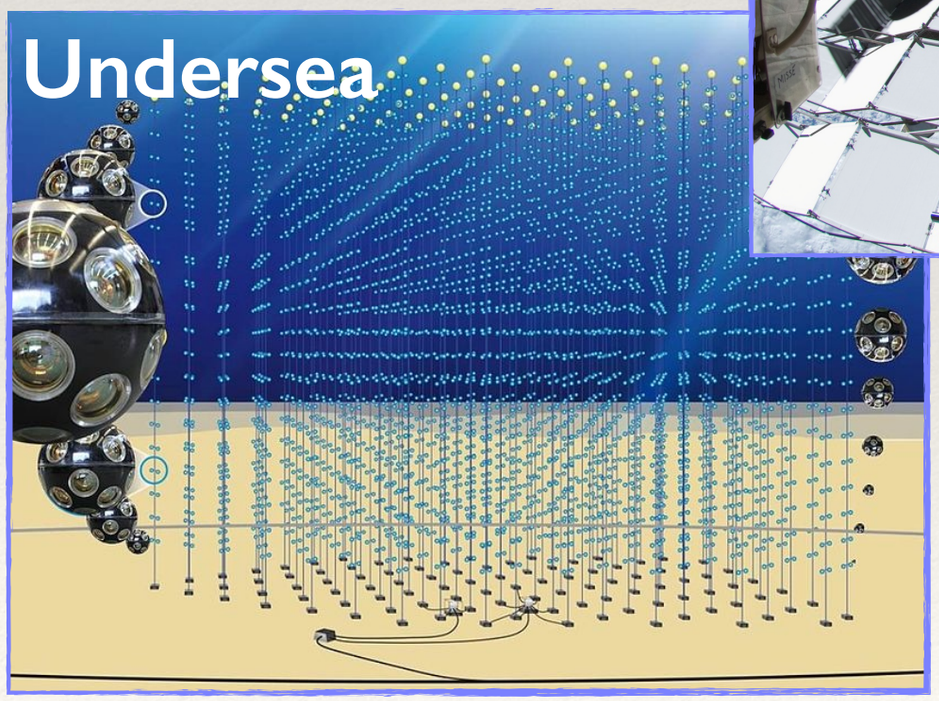
The Dark Universe

DAMA
DARKSIDE-50
DARKSIDE-20t

Many diverse places







Neutrino Physics

ν as a path beyond Standard Model

ICARUS-SBL sterile neutrino search
SOX sterile neutrino search

What is the ν mass ?

HOLMES direct measurement with μ-bolometers
EUCLID indirect measurement with cosmological observations
CUORE
GERDA

ν oscillations (mixing matrix, mass hierarchy, CP violation)

BOREXino solar, geo neutrinos
DUNE CP violation
JUNO mixing, hierarchy
OPERA mixing
T2K mixing, hierarchy, CP
KM3 (ORCA) hierarchy

ν physics

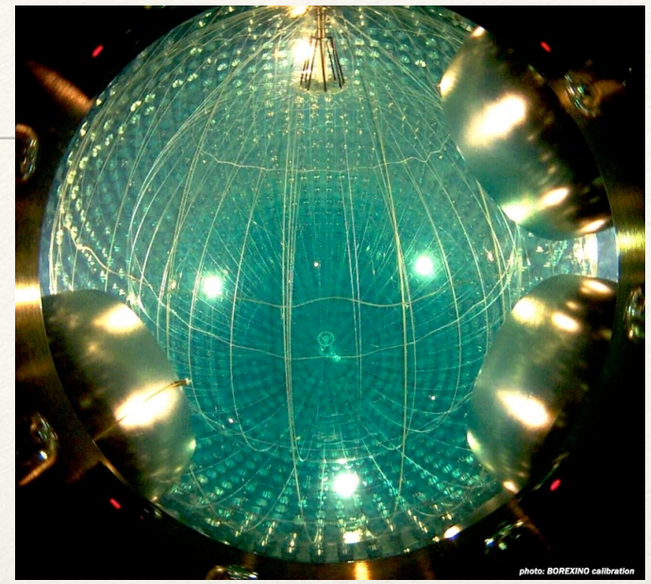
Is ν neutral or charged particle ? (a.k.a. 0νββ decay)

CUORE $^{130}TeO_2$ bolometers, ~230 kg
GERDA ^{76}Ge diodes, ~ 30 kg
LUCIFER/LUMINEU scintillating bolometers, ZnSe and $ZnMoO_4$

ν as a messenger from the Universe

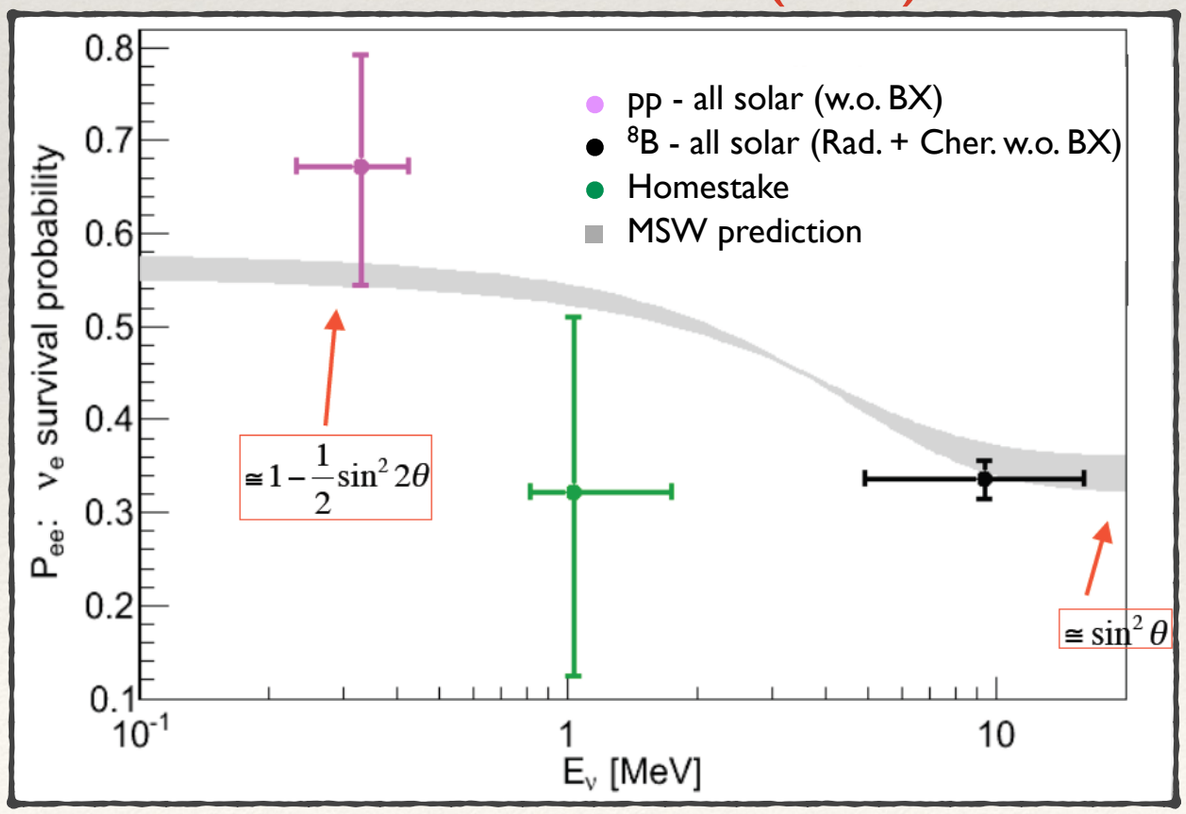
BOREXino solar neutrinos
KM3 high energy ν astronomy
LVD SN watch

BOREXino (@LNGS)

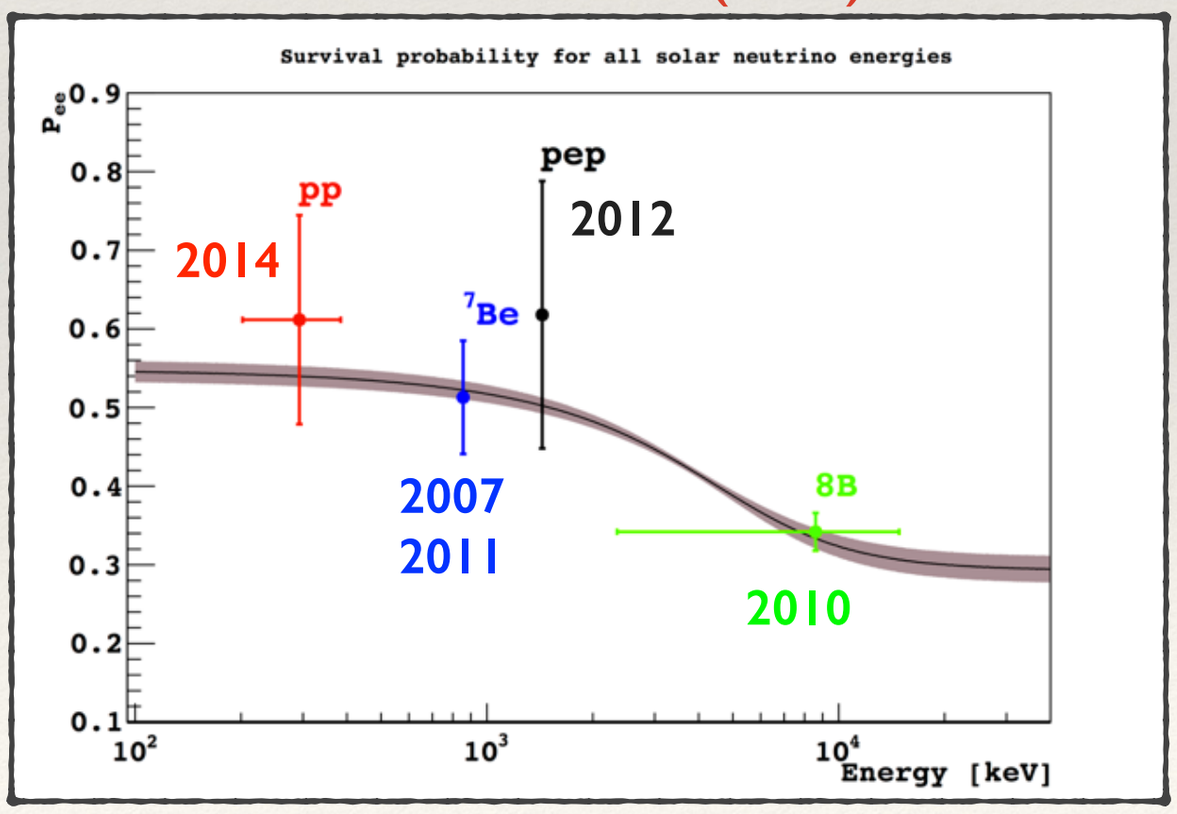


- **A liquid scintillator** detector for solar and geo-neutrinos
- ~ 20 years of collaboration on a very successful project
  - Kurchatov, DUBNA, St. Petersburg, Moscow University (and Kiev)
  - A substantial contribution to construction, data acquisition and data analysis
- **BOREXino** main results (see 6 talks in the afternoon!)

Before Borexino (2006)



After Borexino (2015)

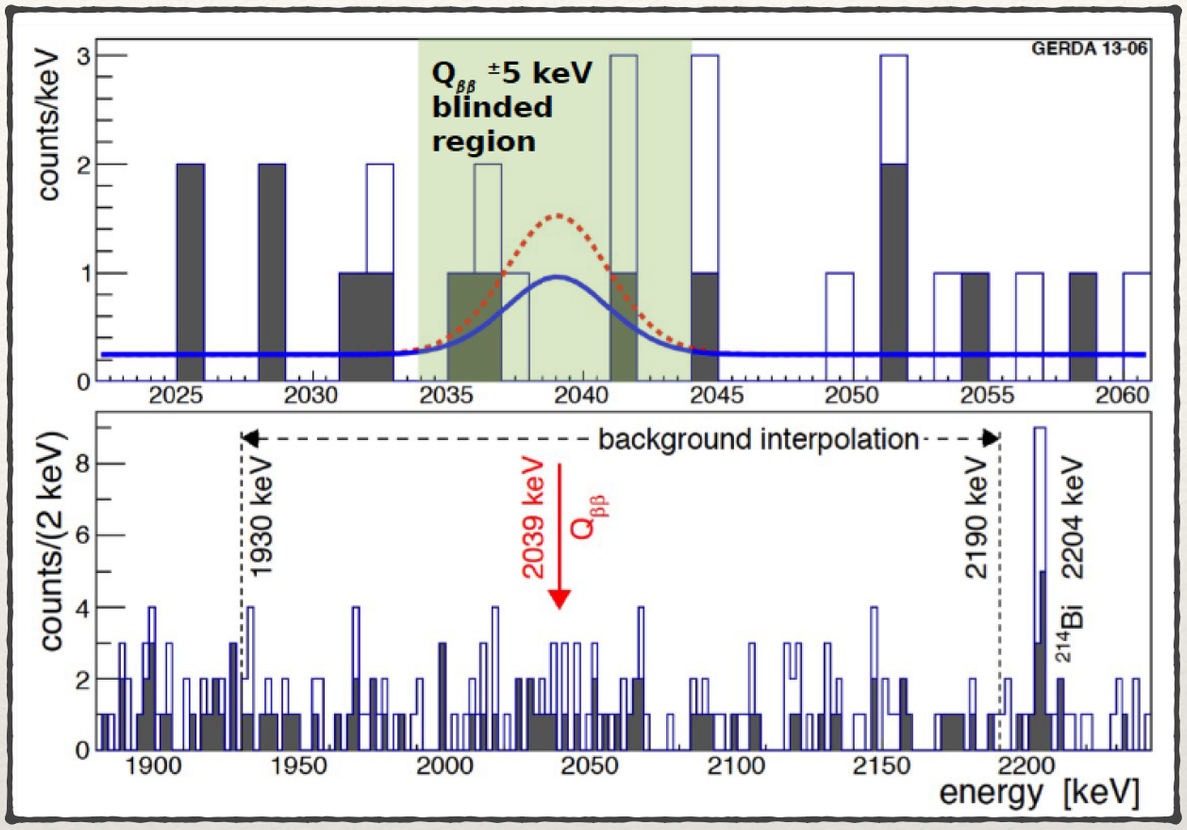


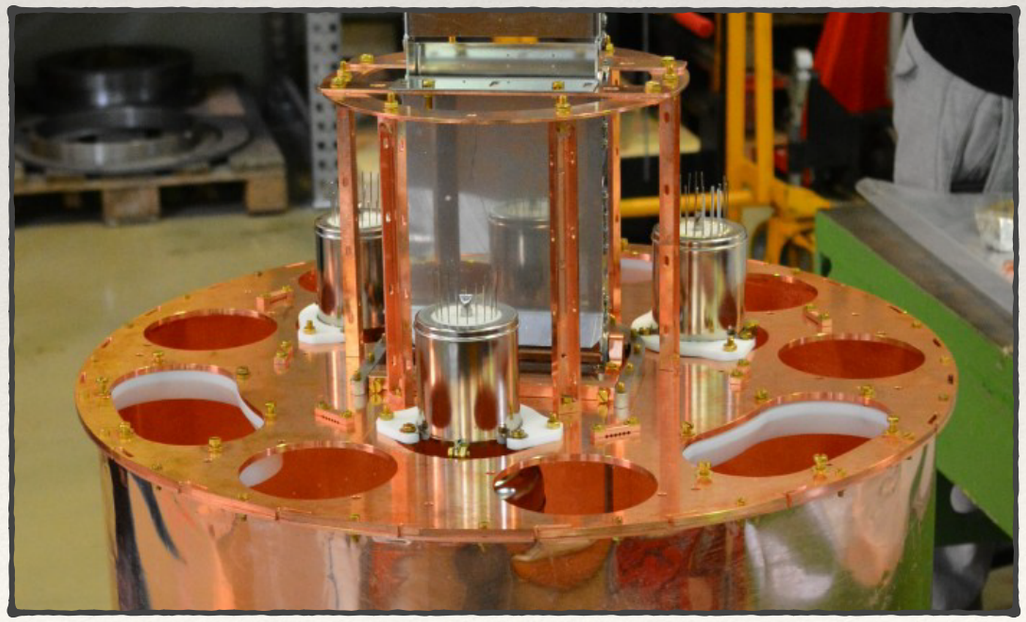
GERDA (@LNGS)

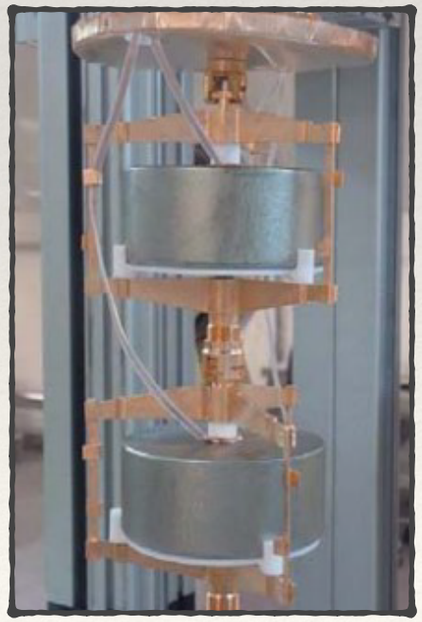
$T_{1/2}^{0\nu} > 2.1\ 10^{25}$ y frequentist

$T_{1/2}^{0\nu} > 1.9\ 10^{25}$ y bayesian

- **Legacy of Moscow-Heidelberg experiments**
- **Successful completion of Phase I**
  - End data taking 21-05-2013
  - Combined with HdM + IGEX
    - p_value $= 2.\ 10^{-4}$
    - Klapdor's claim strongly disfavoured
- **Phase 2 under completion**
  - More mass (detectors done!)
  - Less background (10 times)
  - Improvements in LAr veto
  - Data taking with ~30 kg in a few months







Scintillating Bolometers for 0νββ

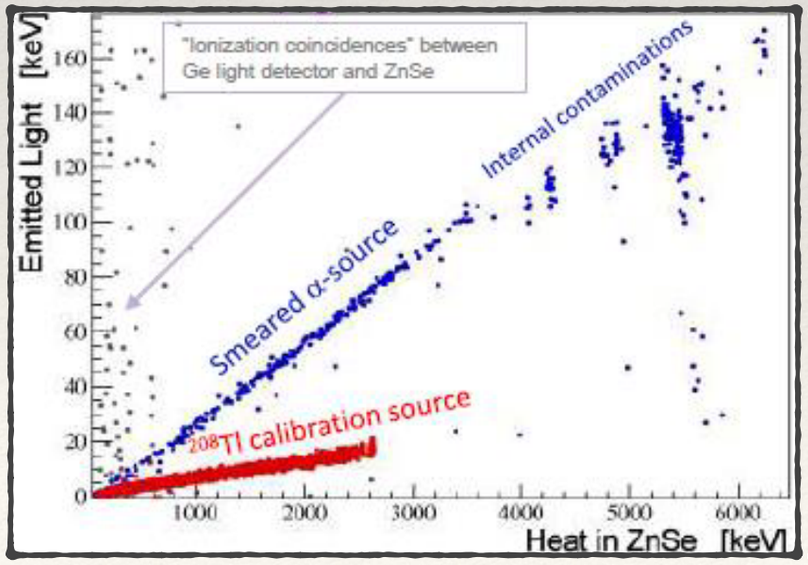
- Current generation of **bolometer** experiments are background limited
  - Option: use scintillation light to reduce α background
  - Test with 20 + 40 crystals (20 @ Modane)
  - Possible technology for a CUORE upgrade
  - A nice opportunity for stronger collaboration with Russian groups

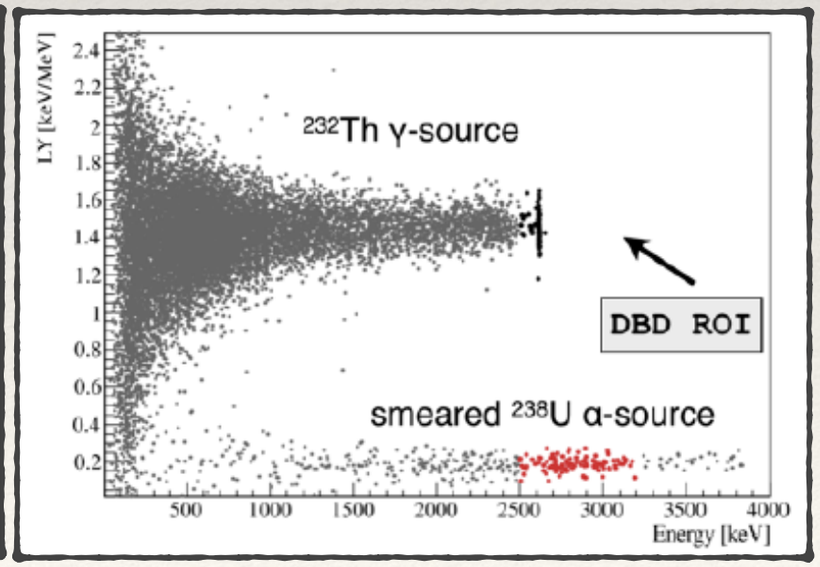
ZnSe crystals (^{82}Se at 95%)

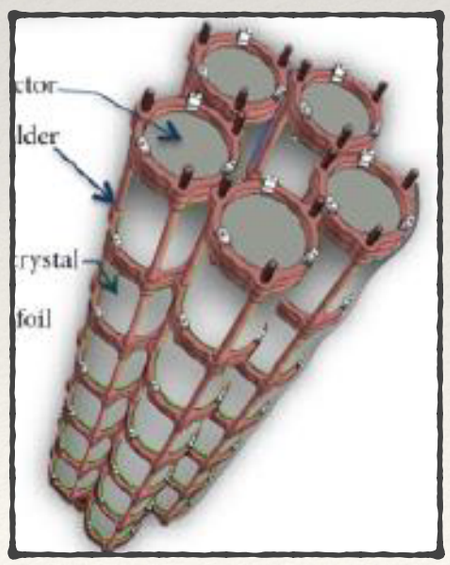
Ucraine

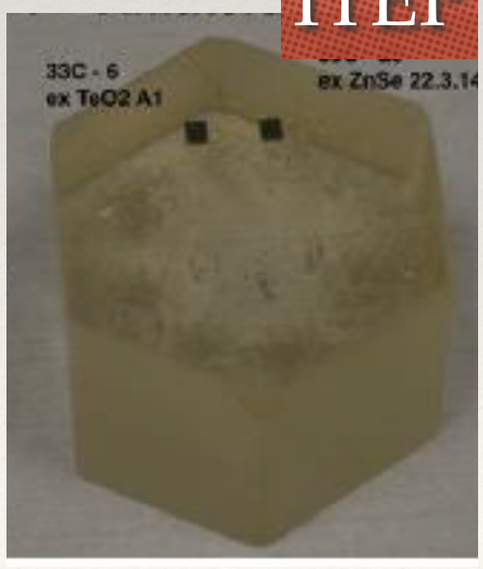
$ZnMoO_4$ crystals (^{100}Mo at 99%)

ITEP



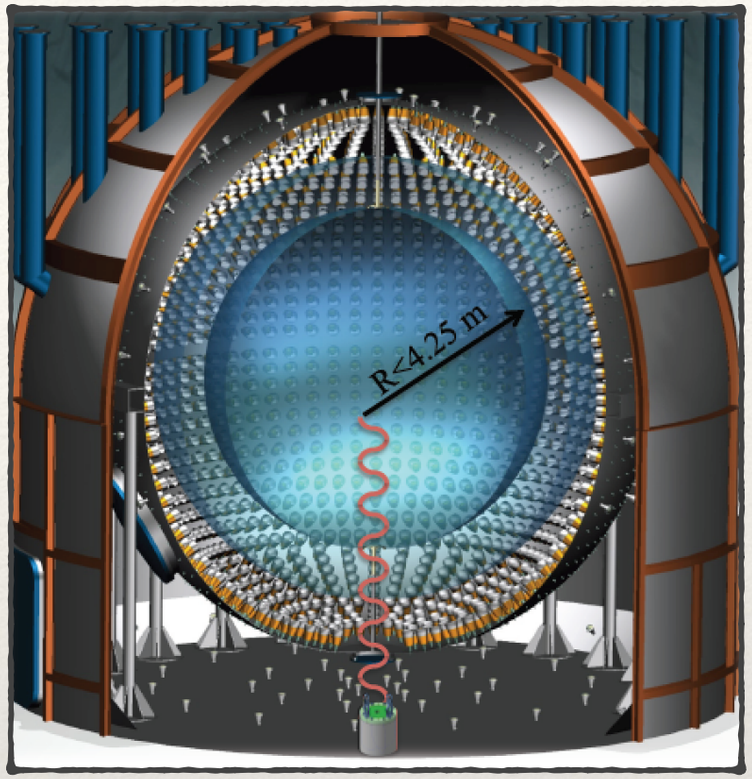






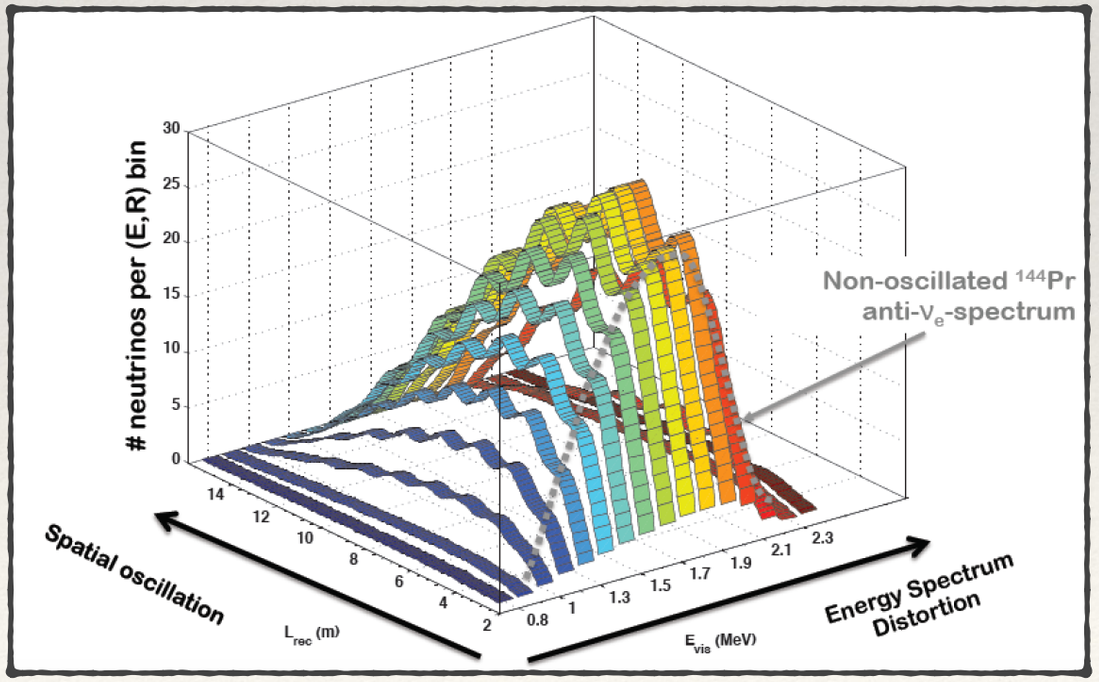
SOX

- A nice re-use of BOREXino detector
  - Search for sterile neutrinos by means of an artificial anti-neutrino (and maybe in the future neutrino) source
  - ^{144}**Ce** anti-neutrino source made in Russia
    - **INFN-CEA project** with active role of **Russian industry** and **scientists**



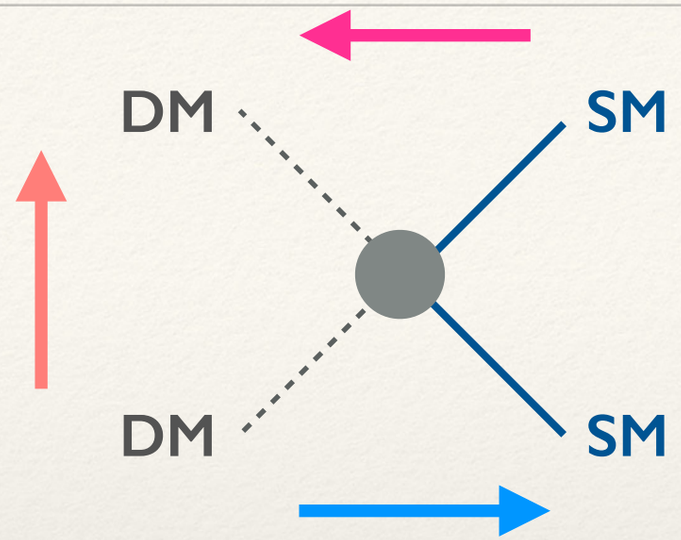
- Similar proposal exists in Russia with SAGE detector
  - ^{51}Cr neutrino source

- Several talks (including my own) in the afternoon on SOX



The Dark Universe

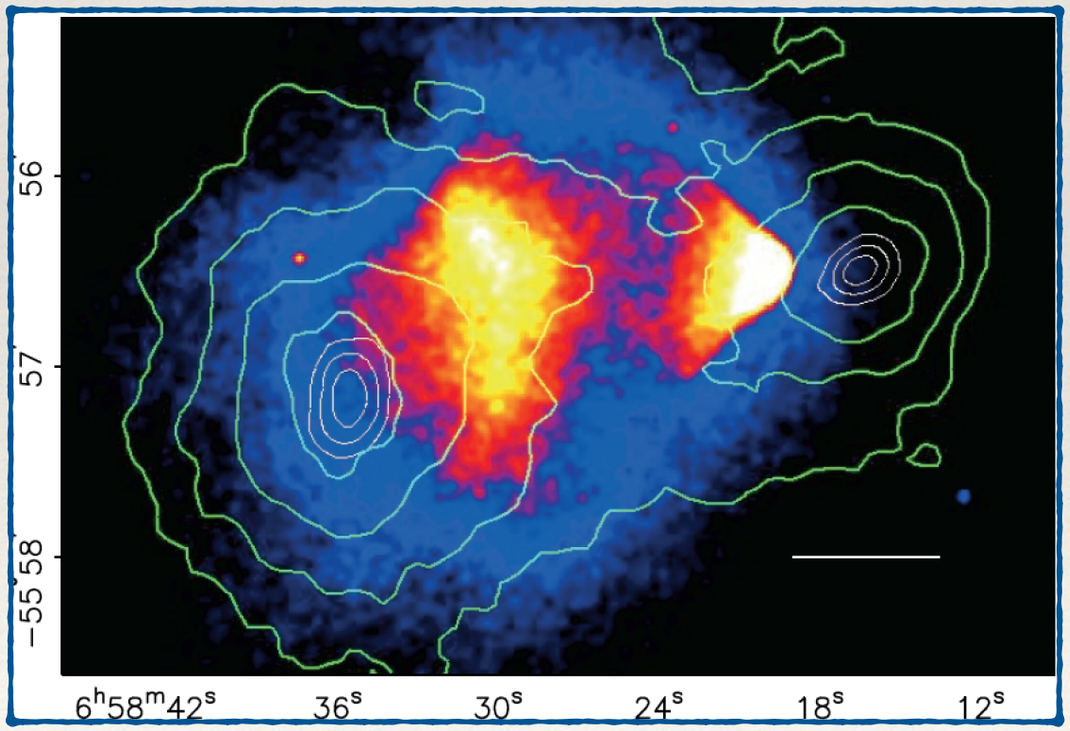
- **Three ways to Dark Matter**
  - **Direct**
  - **Indirect**
  - **Production (LHC)**



SM: Standard Model Particle

DM: Dark Matter Candidate

Unknown Interaction



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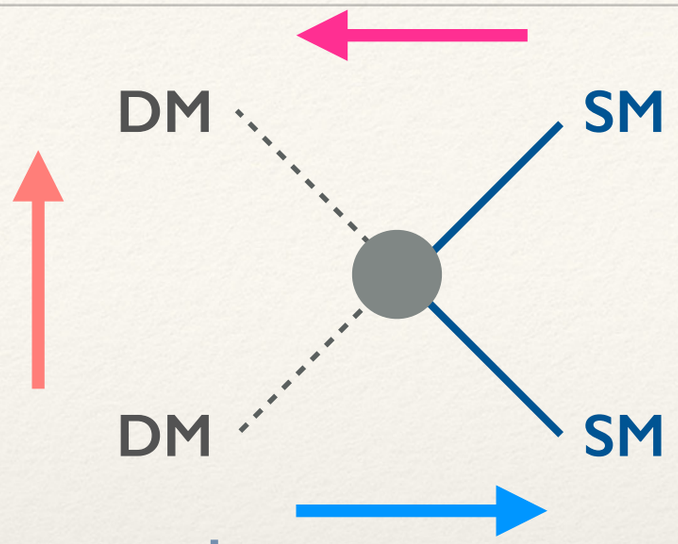

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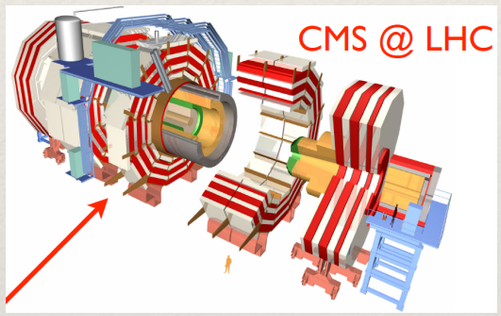
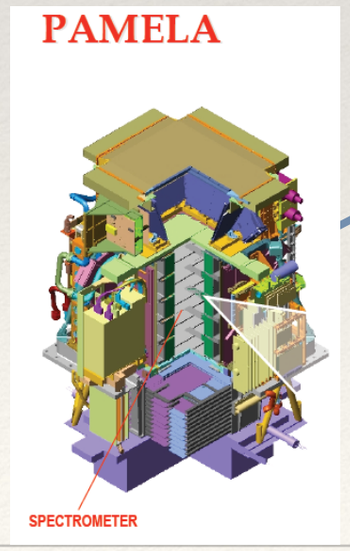


Production
LHC Experiments
(not my job…)

Dark Matter

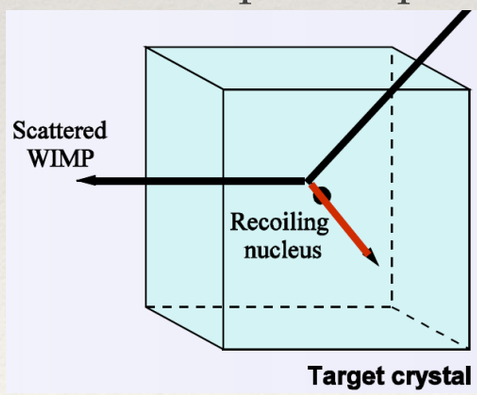
Direct Detection

CRESST	WIMPs
DAMA-Libra	Model Independent
DarkSide-50 (20t)	WIMPs
Xenon1t (multi-ton)	WIMPs, E.M. model dep.
QUAX	Axions, spin coupling



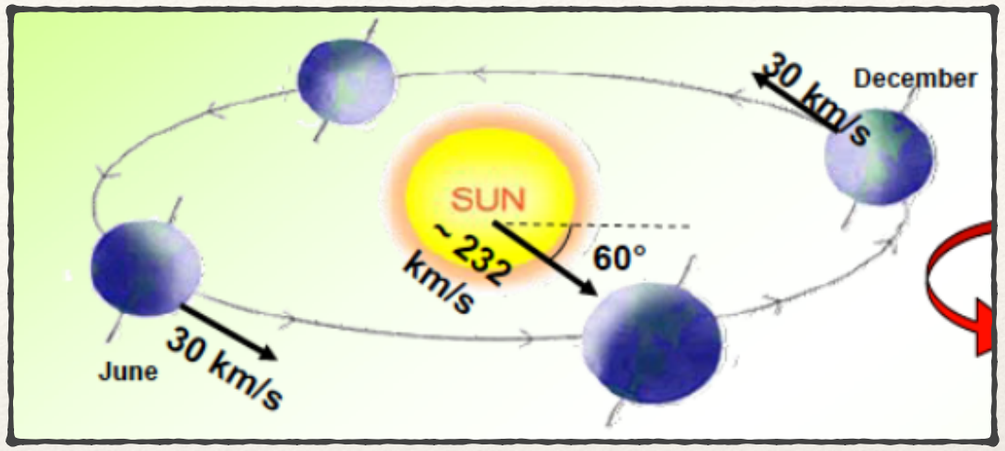
Indirect Direction

AMS-02	p,pbar, $e^{\pm}$	
Dampe	γ,p,pbar, $e^{\pm}$	
Fermi	γ, $e^{\pm}$	
Gamma-400	**??**	possibly killed by ROSCOSMOS
Pamela	**p,p,γ, $e^{\pm}$**	

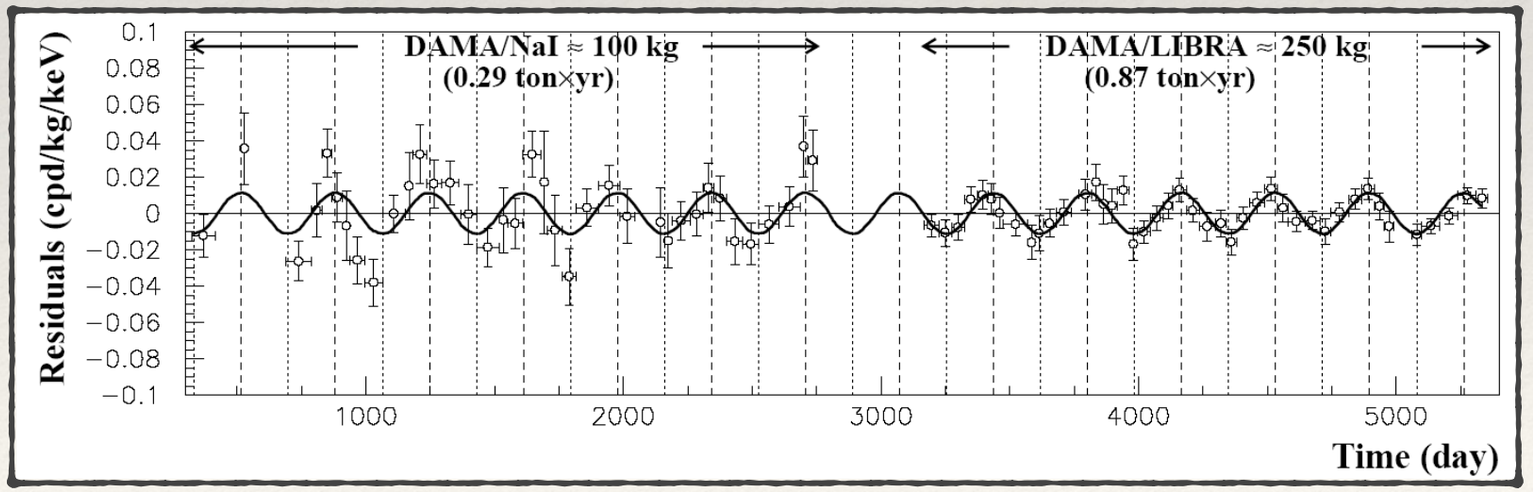


Dama Libra

- **~250 kg NaI** scintillator crystals
  - **Low threshold** (2 keV published, 1 keV data taking in progress)
  - Long standing model independent signal
    - No credible interpretation beyond Dark Matter signature **BUT**
    - Difficult to reconcile with other experiments assuming naïve WIMP or simple electromagnetic interactions (LUX, Xenon-100)

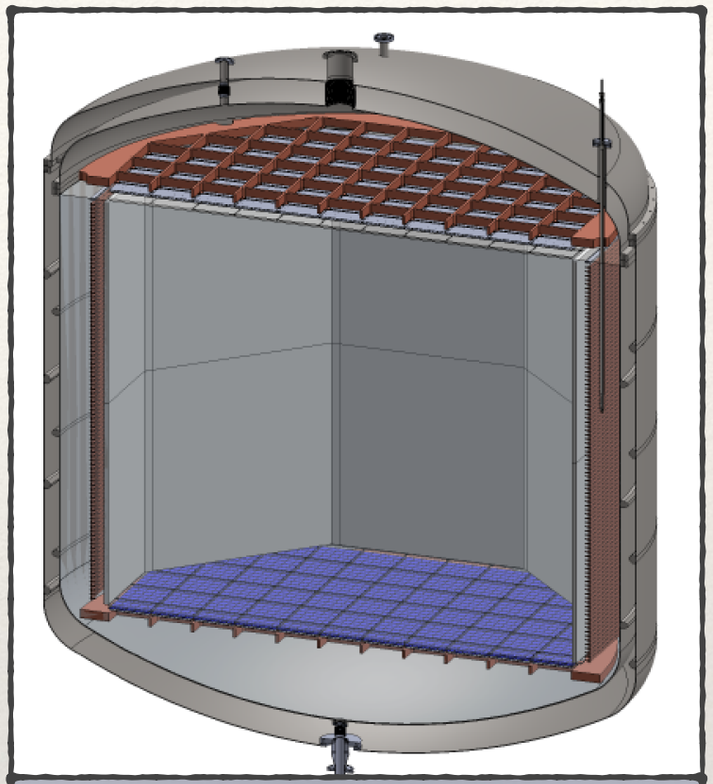


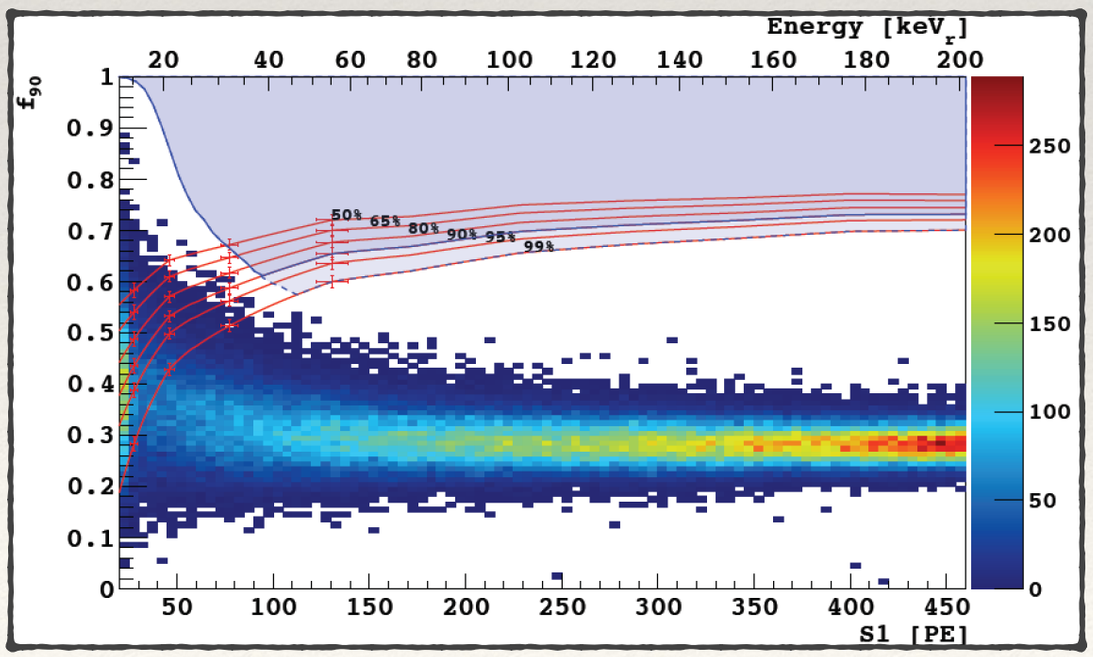
See R. Bernabei's talk



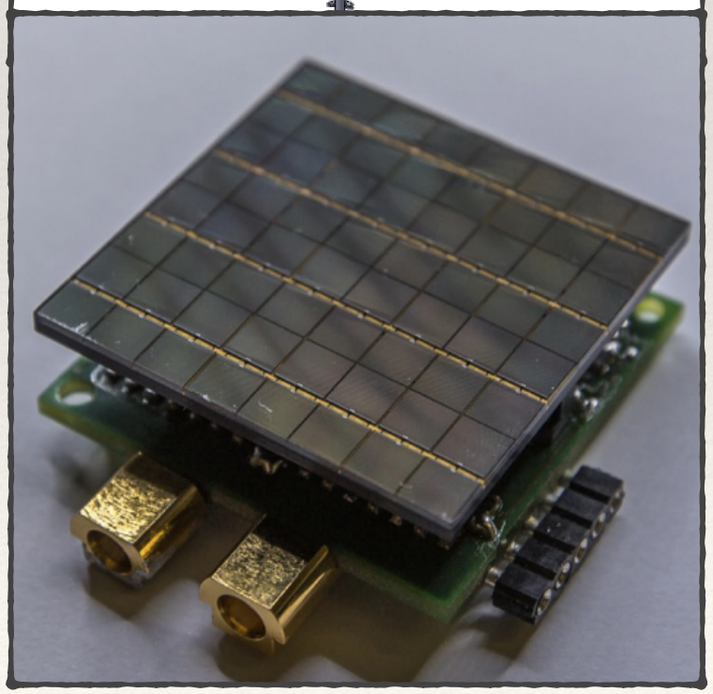
Darkside-50 kg (future 20t)

- **50 kg LAr** bi-phase detector operated with low ^{39}**Ar** and liquid scintillator neutron veto
  - Zero background goal achieved
  - ***20 t phase under discussion***
    - Key contribution from Russia: low background titanium cryostat
    - See several talks on Thursday for details

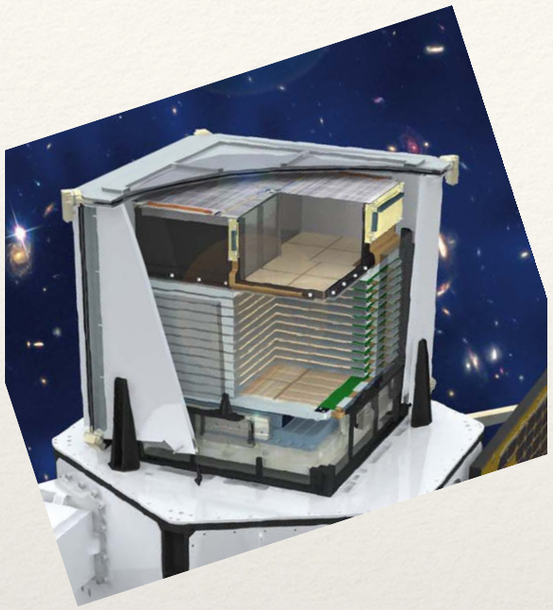




SiPM device under development at FBK (INFN Trento)



Flying detectors



AGILE, 23-4-2006
Mainly X and γ

PAMELA, 15-6-2006
e+, e-, nuclei, anti-p, anti-He

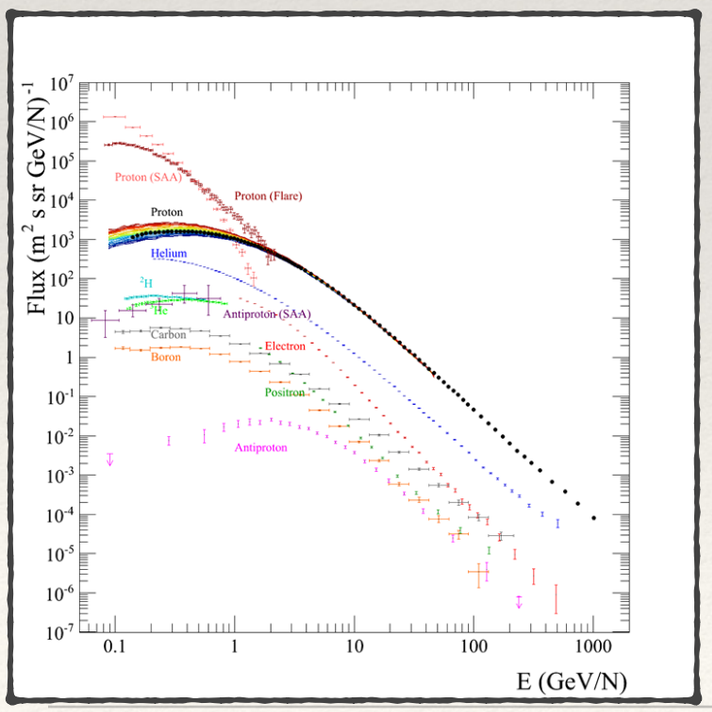
FERMI, 11-6-2008
Brand new γ sky, but also electrons

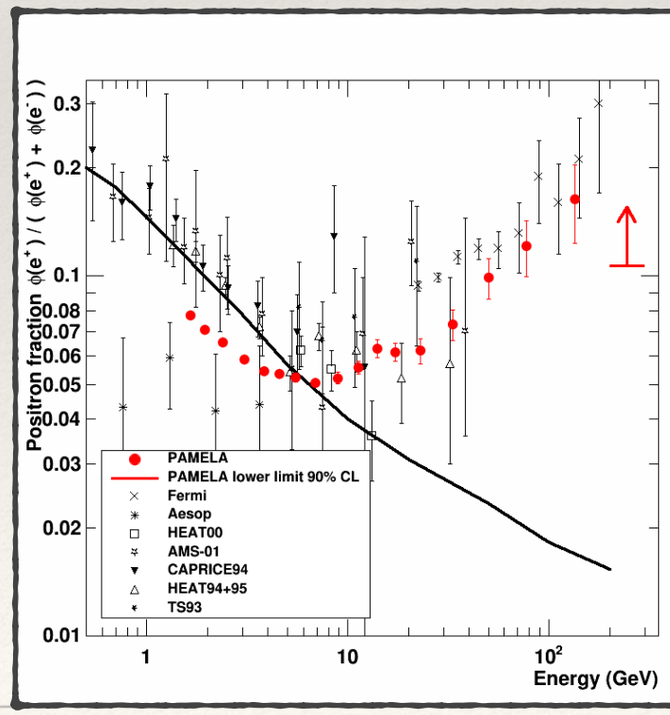
AMS-02, 11-6-2011
Charged particles up to 1 TeV

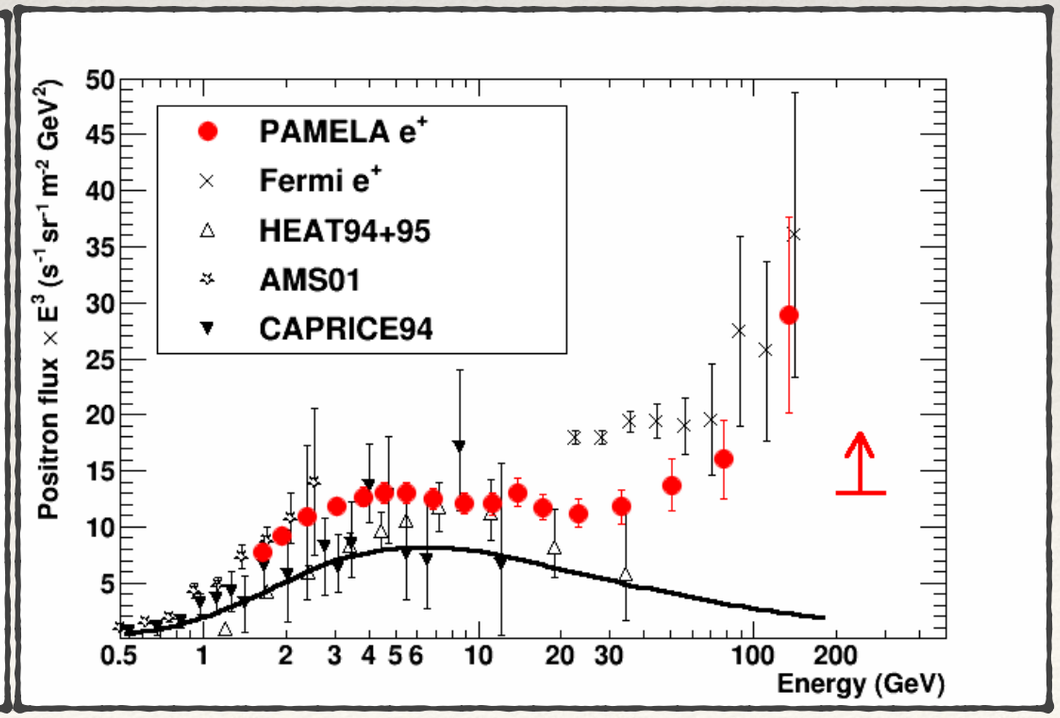
- Among these, Pamela is a nice example of strong joint INFN-Russia collaboration
  - Silicon detectors technology: know how from long standing accelerator experience
  - Data analysis, Detector simulations
  - Leading role (P.I. Piergiorgio Picozza)

Pamela

- Launch **15-6-2006** from Baikonur
  - Stable operation in RESURS-DK1 satellite
    - Conditions are getting worse, but still usable after 9 y in space !
- A very successful experiment
  - Pamela results on DM all confirmed by AMS-02
  - Several talks on Friday on all results obtained in 9 y of data

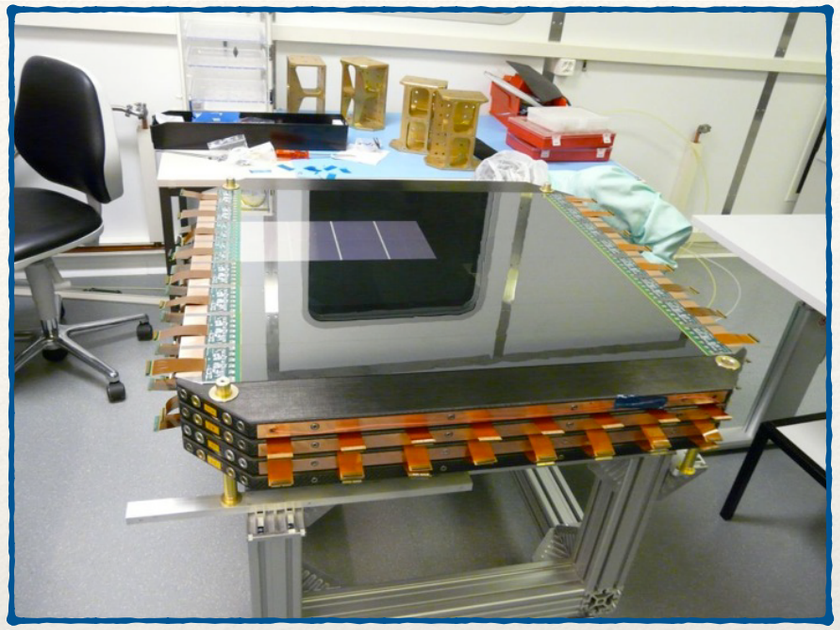


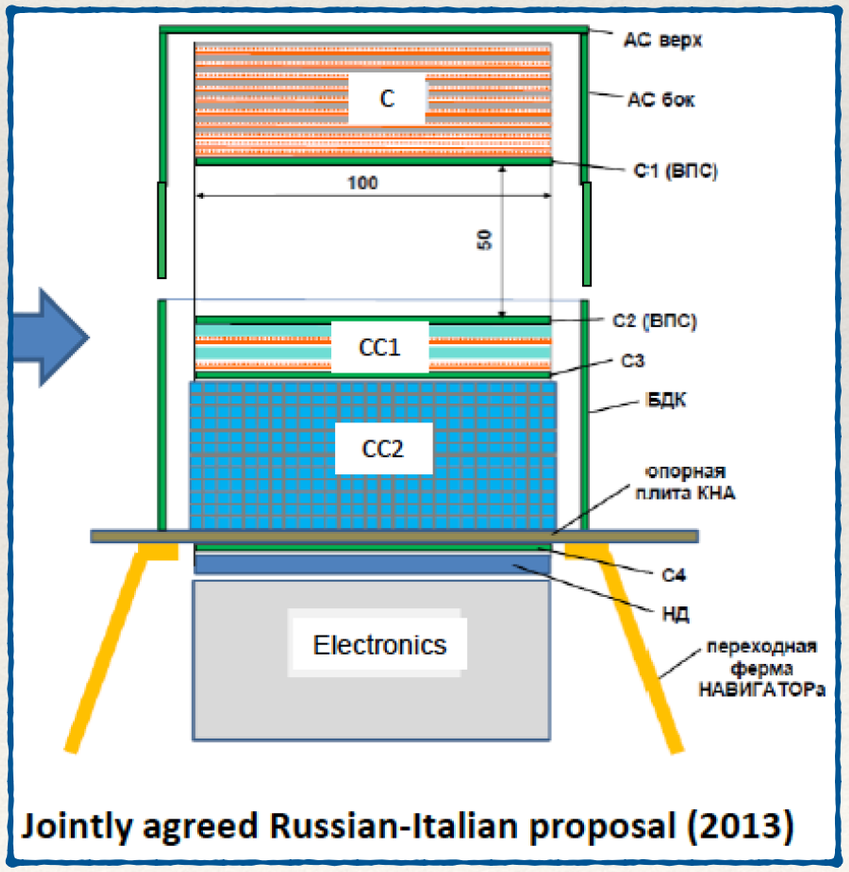




Future space detectors

- Follow up of Agile-Pamela-Fermi-AMS02
  - **Dampe (China)**
    - Important synergy with CAS. Chinese fundings.
      - **2 GeV - 10 TeV e/γ** **30 GeV - 100 TeV CR**
    - Almost ready to fly
  - **Gamma-400 (killed ???)**
    - Tracker + Innovative calorimetry (CaloCube)
      - **100 MeV - 1 TeV e/γ** 2% energy resolution,
        10 TeV e^- Light nuclei up to the knee 1000 TeV
        - Excellent hadron / electron separation
      - **High acceptance calorimeter**
  - **HERD**
    - INFN R&D effort just starting now

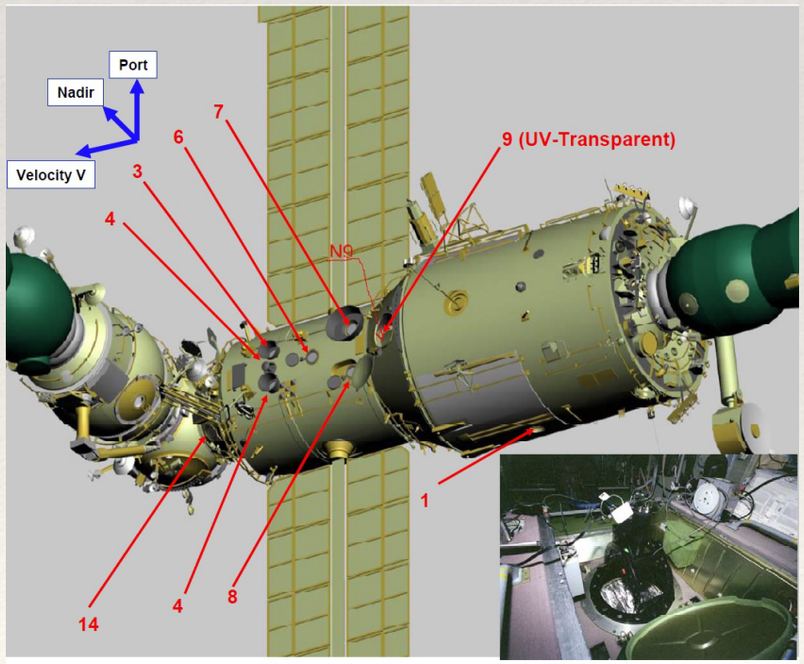


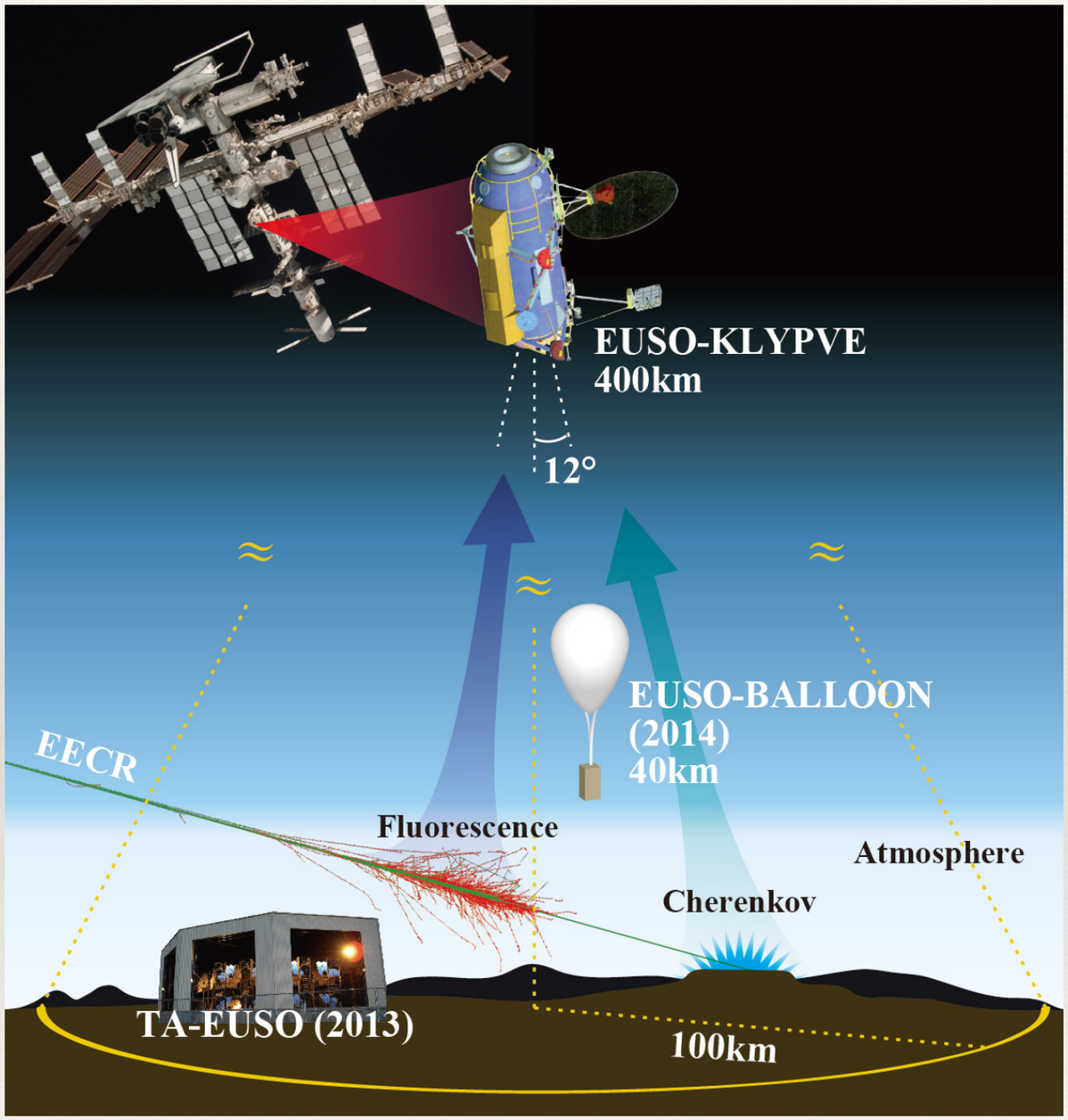


Jointly agreed Russian-Italian proposal (2013)

A dream: observation of CR from space

- A 20 y old dream
  - Fluorescence and Cherenkov detection of CR air showers from space
  - AirWatch, EUSO, JEM-EUSO all dead….
  - Is there a future ?
- Next step: MiniEuso on ISS-Russia ?





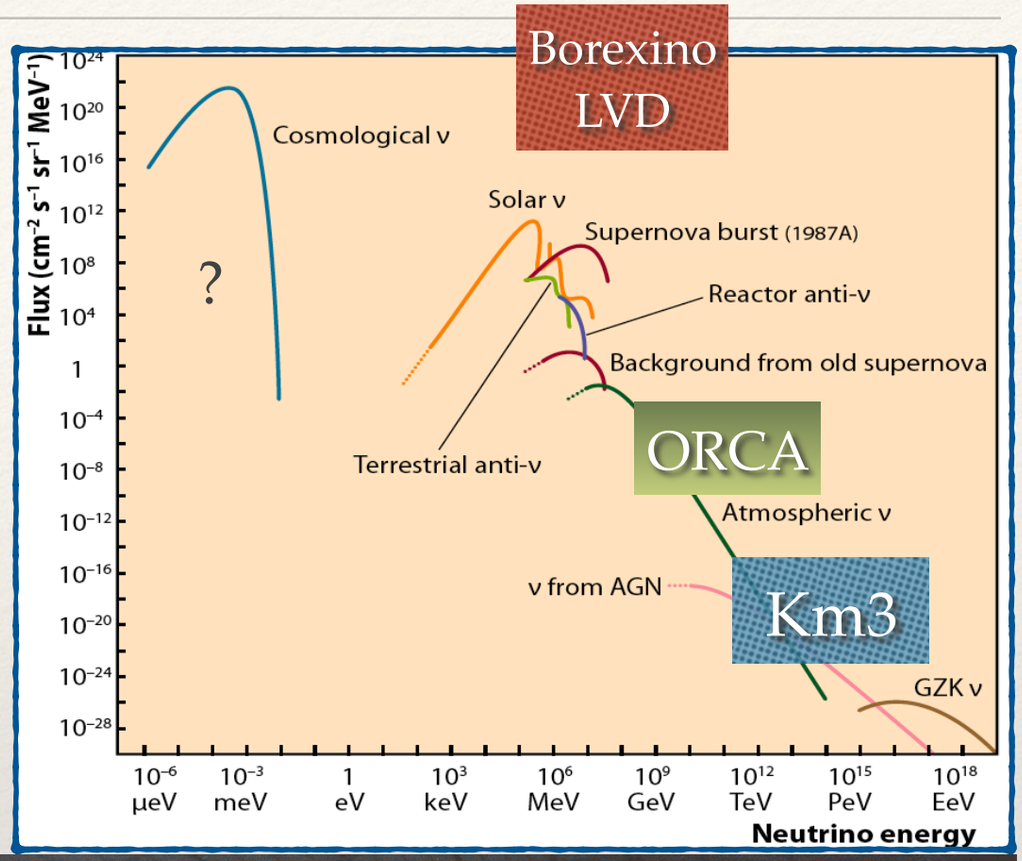
High energy neutrinos

- After **Ice Cube discovery,** increased interest for a high energy neutrino observatory in the Mediterranean
  - **24 M€** investment close to completion.
  - **8 towers and 24 strings will be deployed in water in 2015/2016**
    - New fundings necessary to complete
      - Proposal for additional regional fundings under discussion

- Synergy with Toulon site on **ORCA**
  - ORCA may find neutrino hierarchy, if done on time
  - Waiting for good news from France

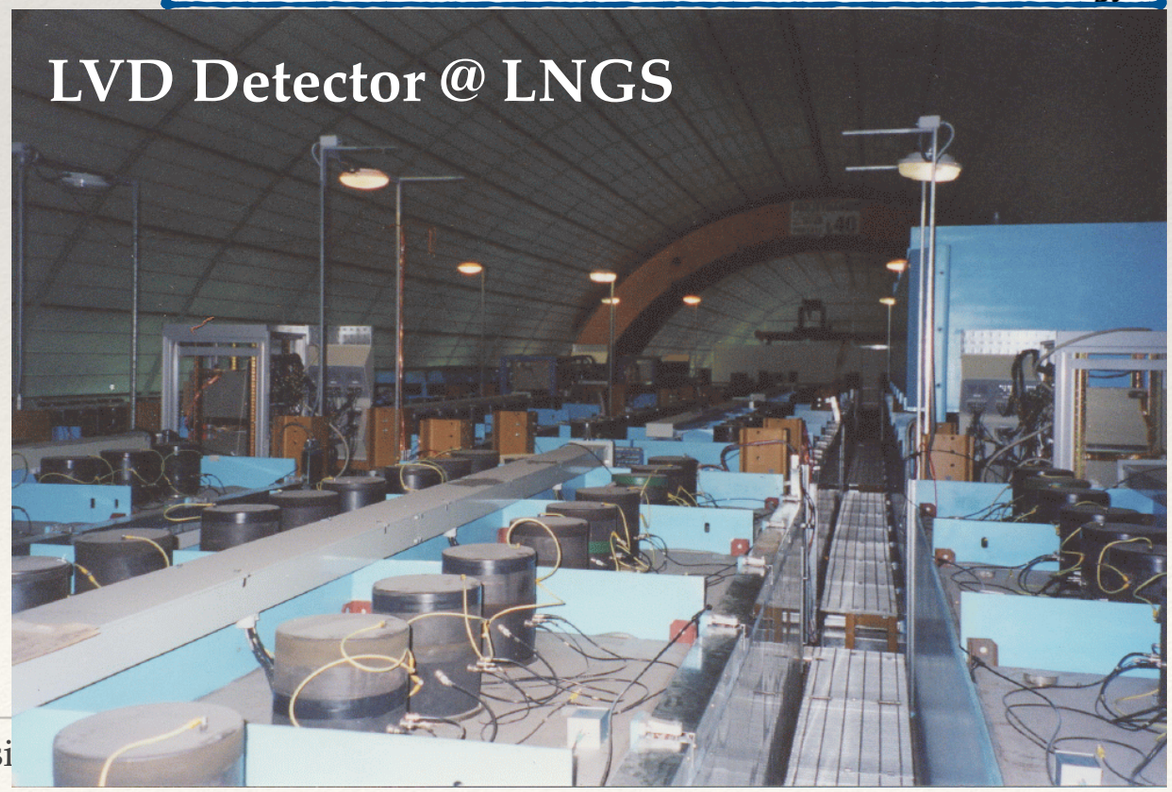
Neutrinos

- Low energy neutrinos (solar, SN, terrestrial) covered by **Borexino** / **LVD at LNGS**
- **Deep sea detectors for:**
  - Neutrino astronomy in the Mediterranean: **Km3Net**
  - Atmospheric neutrinos (hierarchy): **ORCA**
- Both **high priority,** only partially funded so far
  - Work in progress

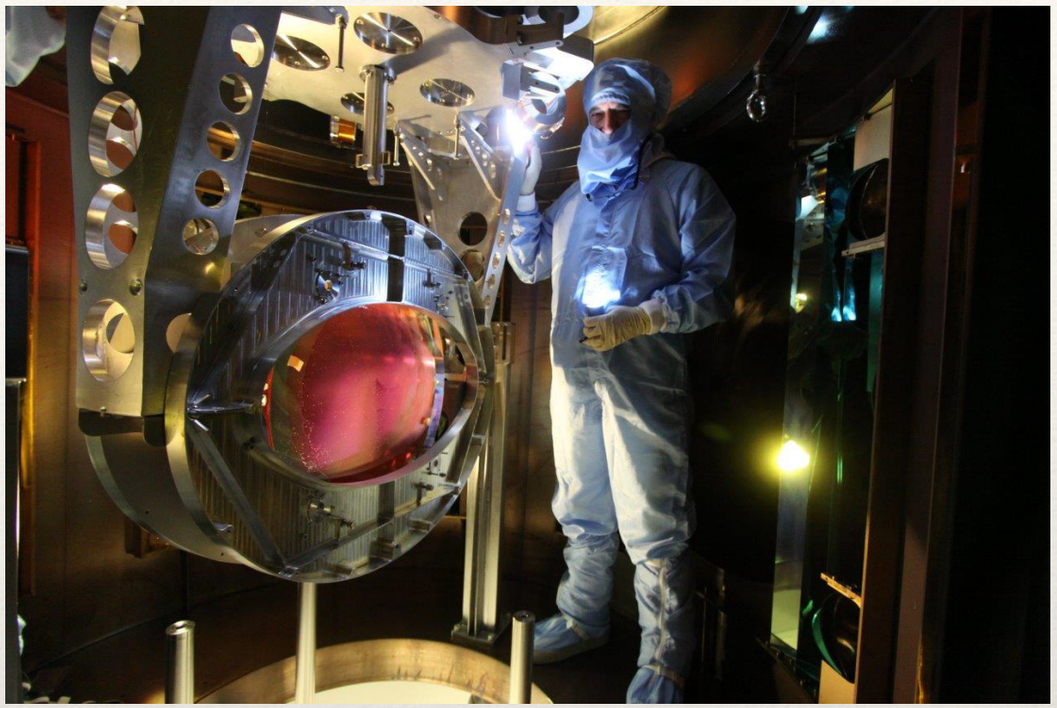


Tower (2014)

Optical Module



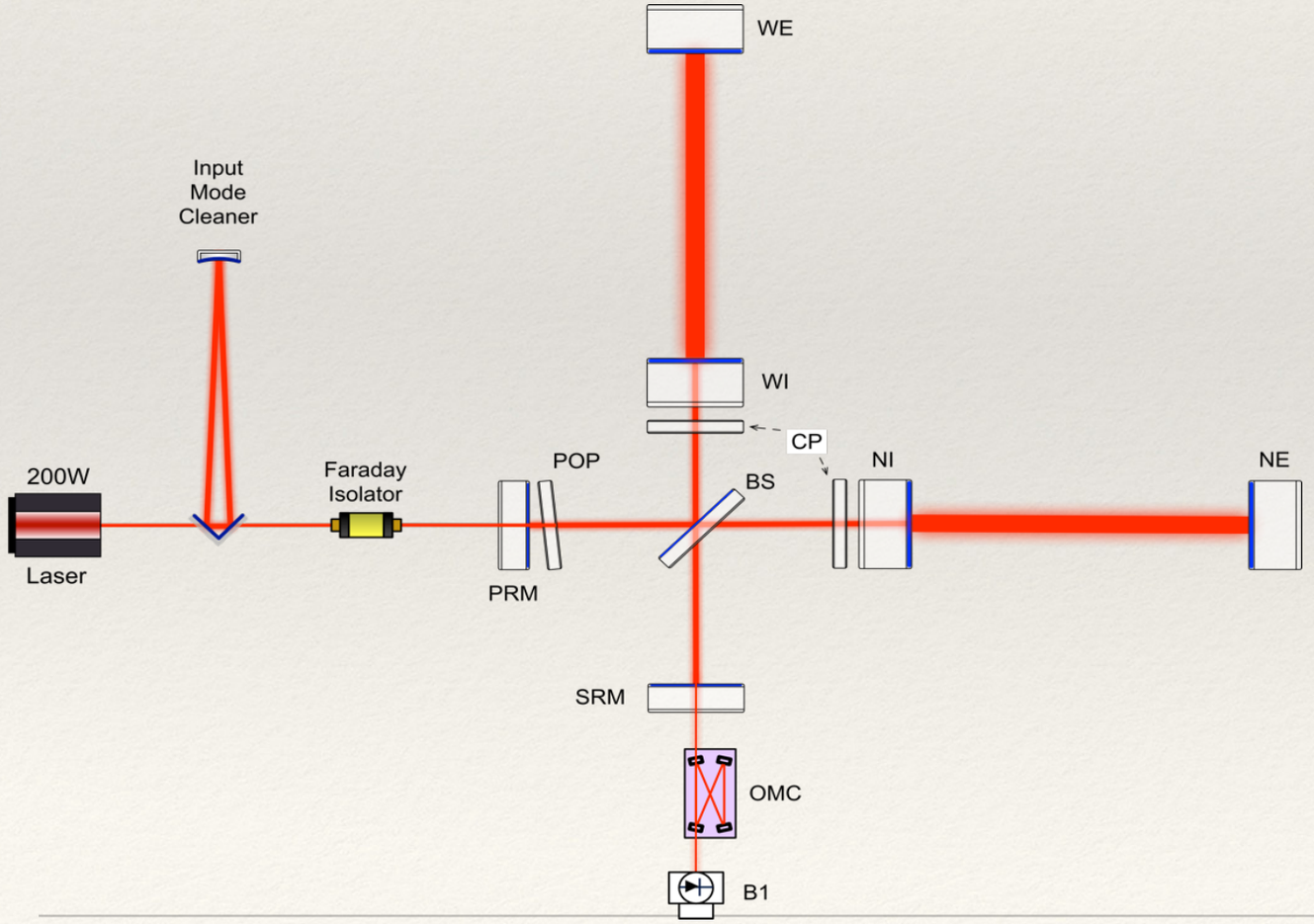
Gravitational waves



- **Step 1: we need discovery!**
  - **Virgo-Ligo** Adv. program almost ready to go
- **Step 2: Birth of GW astrophysics**
  - How many events with Adv detectors ?
    - Large uncertainty: 0.4 < events < 400 y
  - Future
    - Einstein Telescope for relatively high frequency observatory
    - LISA-PF ready for launch: key step toward low frequency observatory
- Multi-messenger observation with GW might be real in the next decade
  - Joint effort with optical, radio, γ, neutrino detectors
- R&D effort for new technologies (atom interferometry on ground or space)

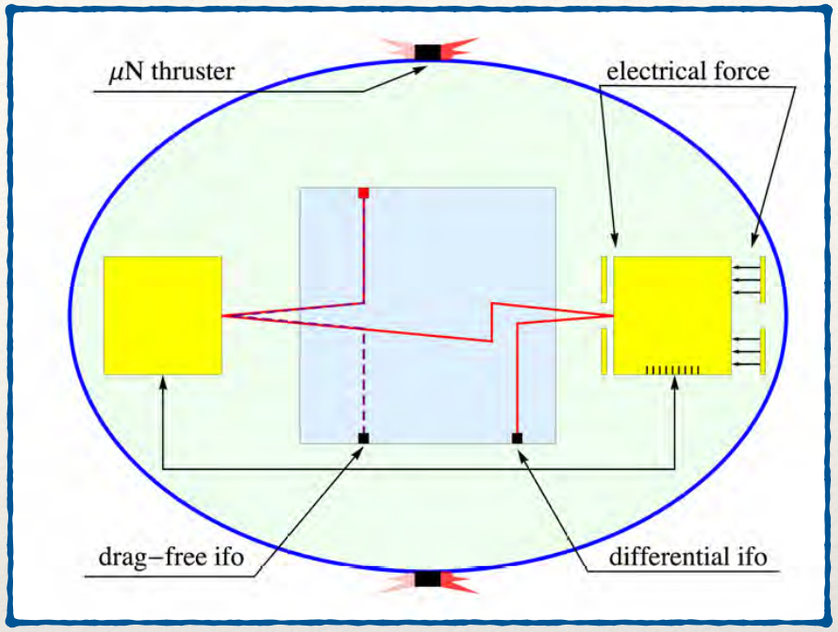
Virgo Advanced

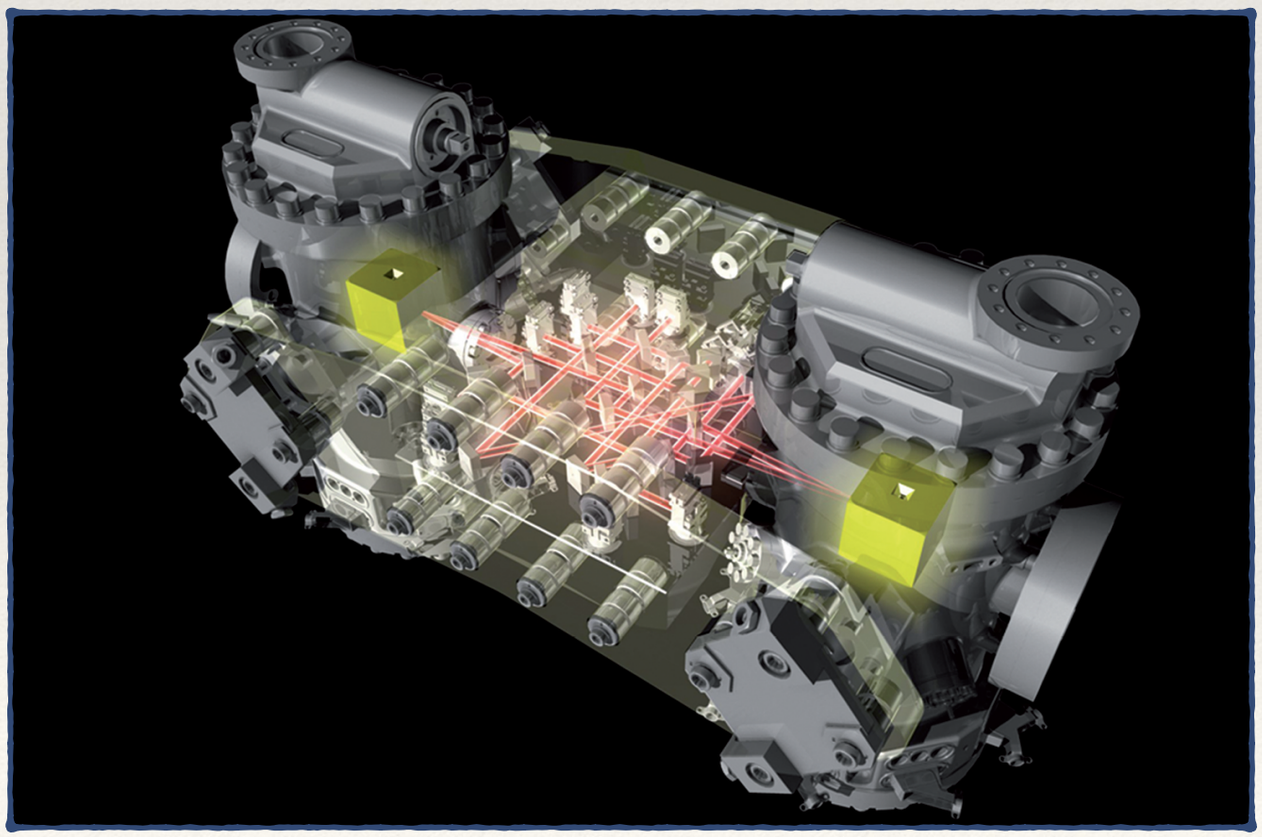
- One of the main INFN efforts
  - EGO + CSN2
  - Strong synergy and agreement with LIGO
  - ~ 8M€/y
  - We must find waves …… Ready for data in 2016

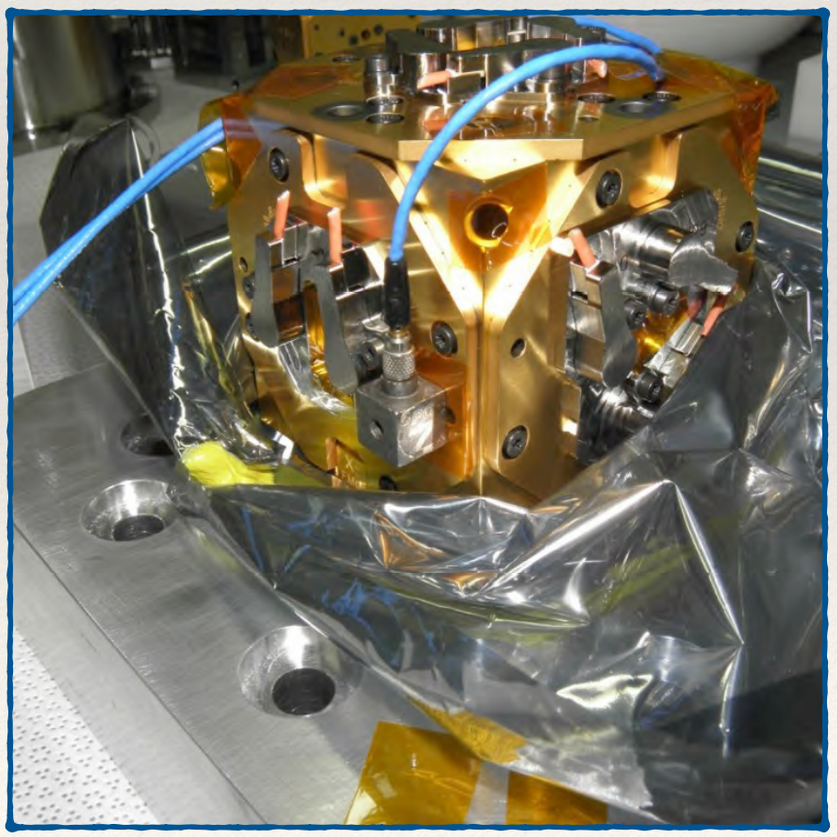


LISA-PF

- Goal: **validate the concept of "no-touch" satellite**
- Two Au-Pt masses in the same satellite
  - One free falling, the second one controlled by low-frequency electrostatic system
  - Launch in Dec. 2015







Conclusions

- A long standing and fruitful collaboration in many diverse fields of research
- Large Russian contribution to Gran Sasso experiments especially, but also to many other
- A rich menu of new projects for future even more intense collaboration

Thanks