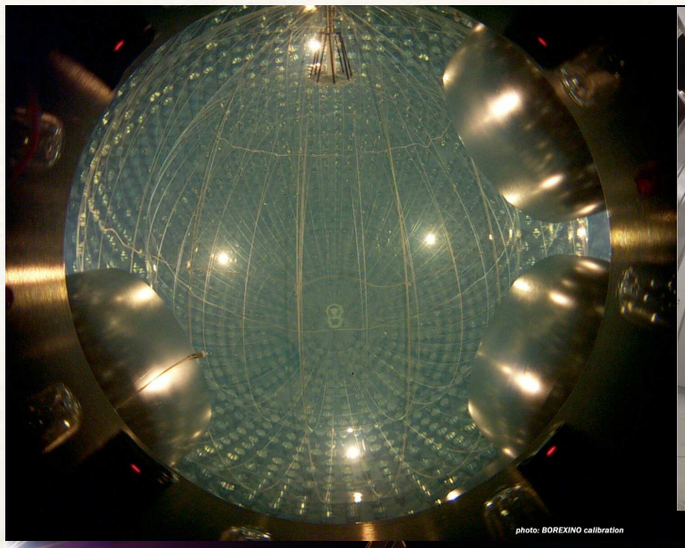
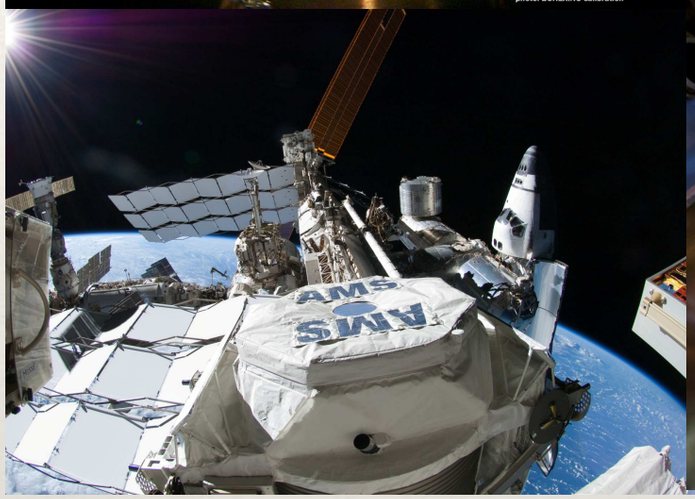
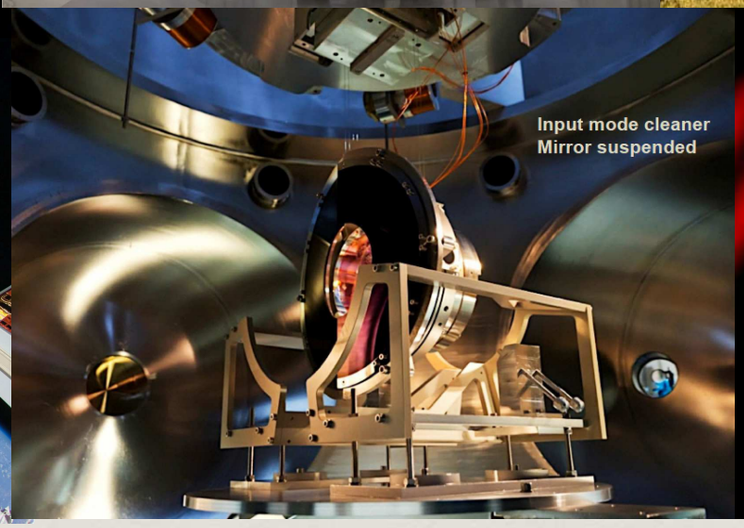
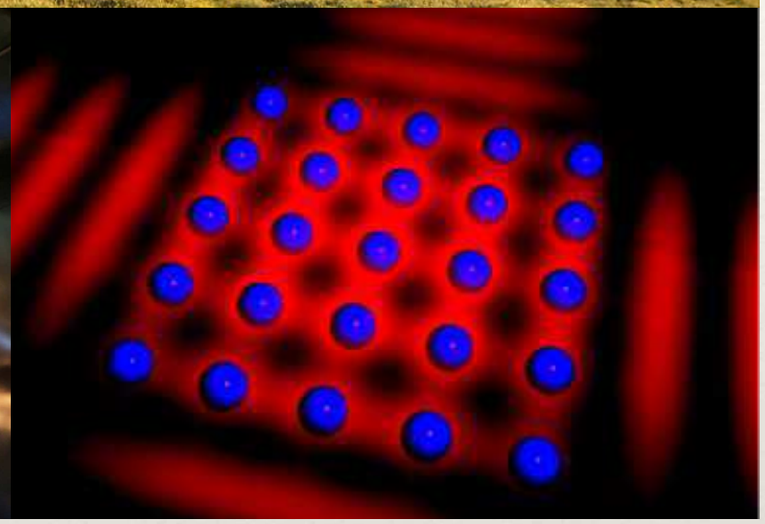








Vulcano Workshop 2016 - May. 23rd, 2016 - Eolie

Astroparticle Physics 2020: INFN perspective and programs

Prof. Marco Pallavicini

Chair of INFN Astroparticle and Fundamental Physics Commission II

Università di Genova & INFN

Astroparticle Physics @ INFN

- Four broad areas

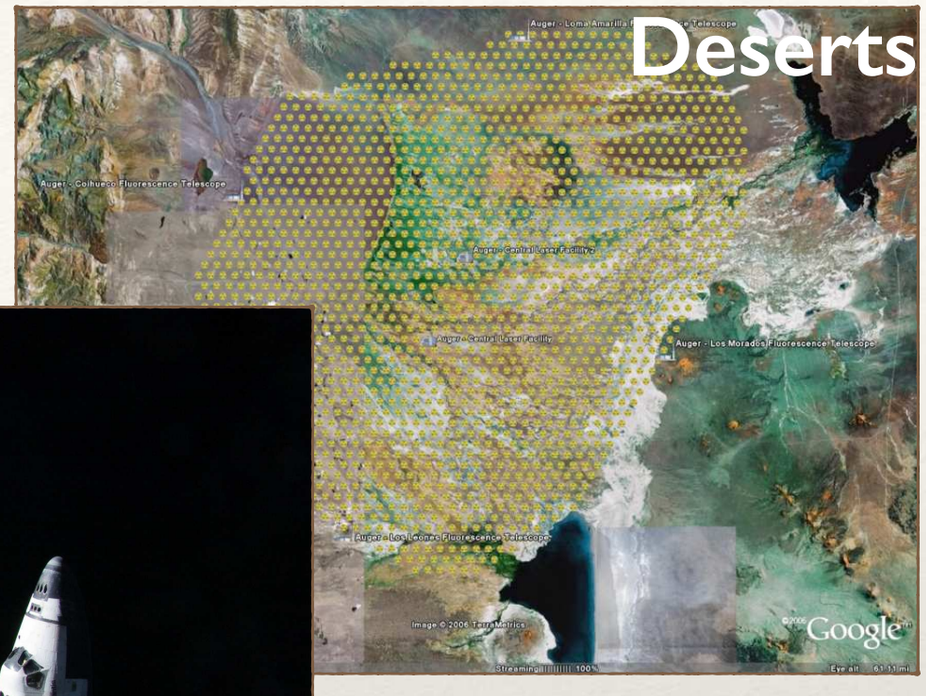
Neutrino Physics

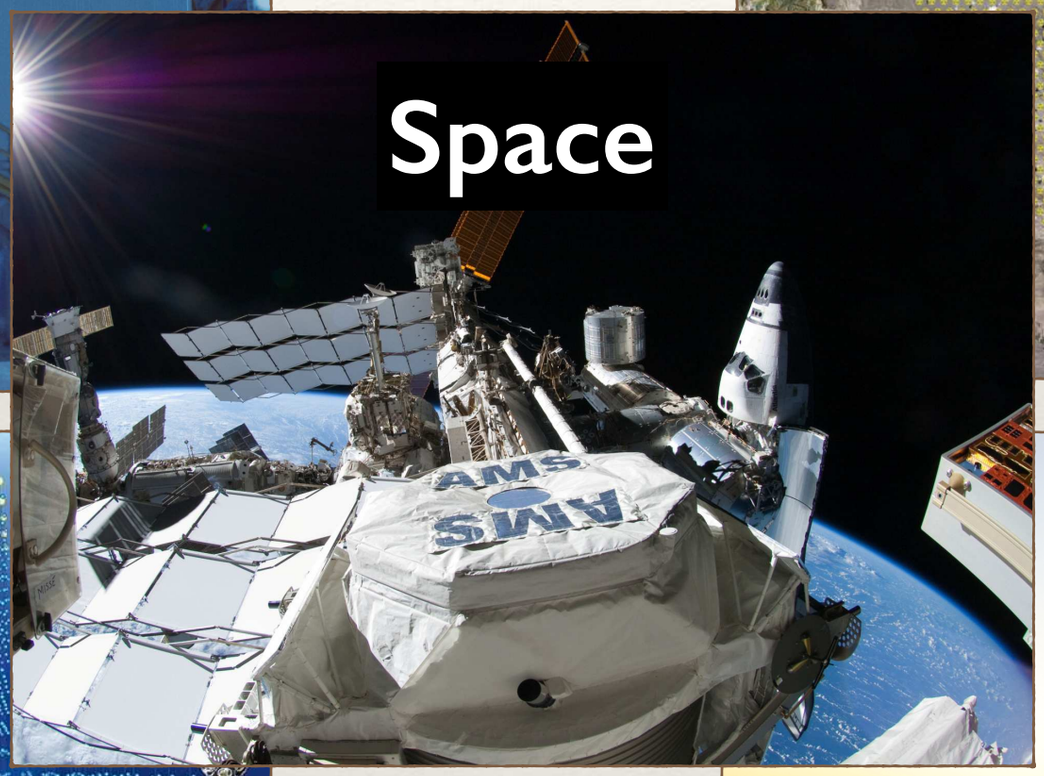
Radiation from the Universe

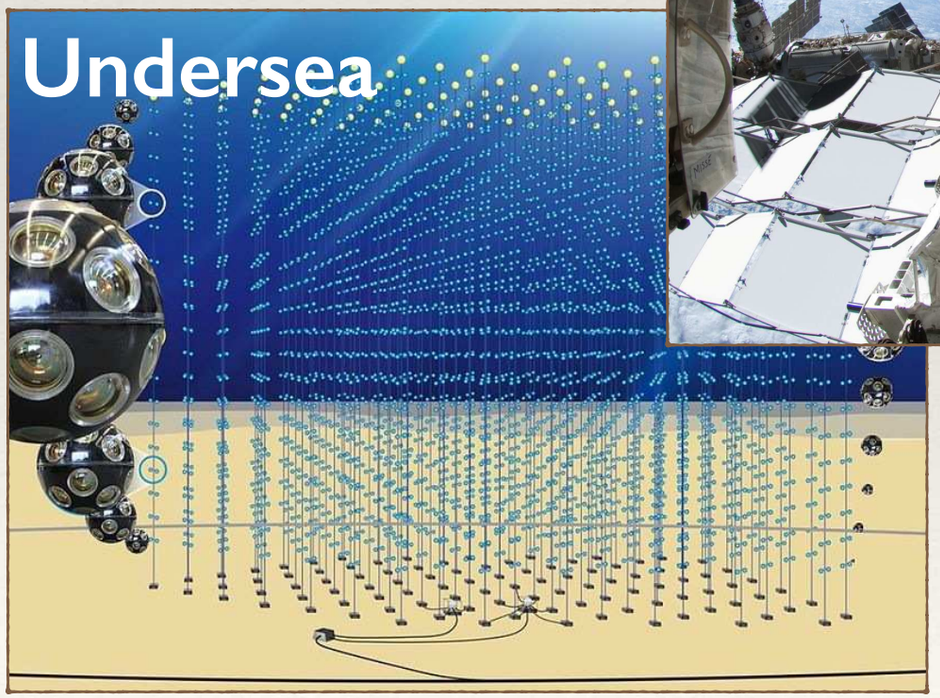
Gravitational waves, Gravity and Quantum Physics

The Dark Universe

Many diverse places







Science: Neutrino Physics

9 projects
BOREXino
CUORE
(CUPID)
DUNE
GERDA
HOLMES2
ICARUS-SBL
JUNO
T2K

Neutrino Physics

Radiation from the Universe

Gravitational waves, Gravity and Quantum Physics

The Dark Universe

Neutrino Physics: aerial view

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

ν oscillations (PMNS, hierarchy, CPV)

BOREXino solar, geo neutrinos
DUNE CP violation
JUNO mixing, hierarchy
T2K mixing, hierarchy, CP
KM3 (ORCA) hierarchy
ENUBET flavour tagging in beams

ν as a messenger from the Universe

BOREXino solar neutrinos
KM3 high energy ν
(waiting funds) astronomy
LVD SN watch

Majorana or Dirac ? (a.k.a. 0νββ decay)

CUORE $^{130}TeO_2$ bolometers, ~230 kg
GERDA-II ^{76}Ge diodes, ~ 30 kg
CUPID new techniques, scintillating bolometers, ZnSe and $ZnMoO_4$

Running
Under construction
Future planning
Closing

Neutrino oscillations: global view

- Long term projects (world wide): **JUNO**, **HK (T2HK)**, **DUNE**
  - Likely, nothing else in the next 15 years (except PINGU & ORCA for mass hierarchy)

- **Does it make sense to contribute to all three ?**
  - **Yes, in principle.** Physics programs are diverse, rich, and complementary.

✔ • **JUNO** is based on technology and know-how developed by INFN for Borexino Jun Cao Tue

? • **HK (T2HK):** Water Cherenkov has proven to be extremely successful and still can be

? • **DUNE** is the natural evolution of liquid Argon technology, mostly developed at Gran Sasso

- Can we do it ?
  - **With existing resources, probably not,** at least with relevant contributions
    - Not enough people.
    - Not enough resources.

$0\nu\beta\beta$

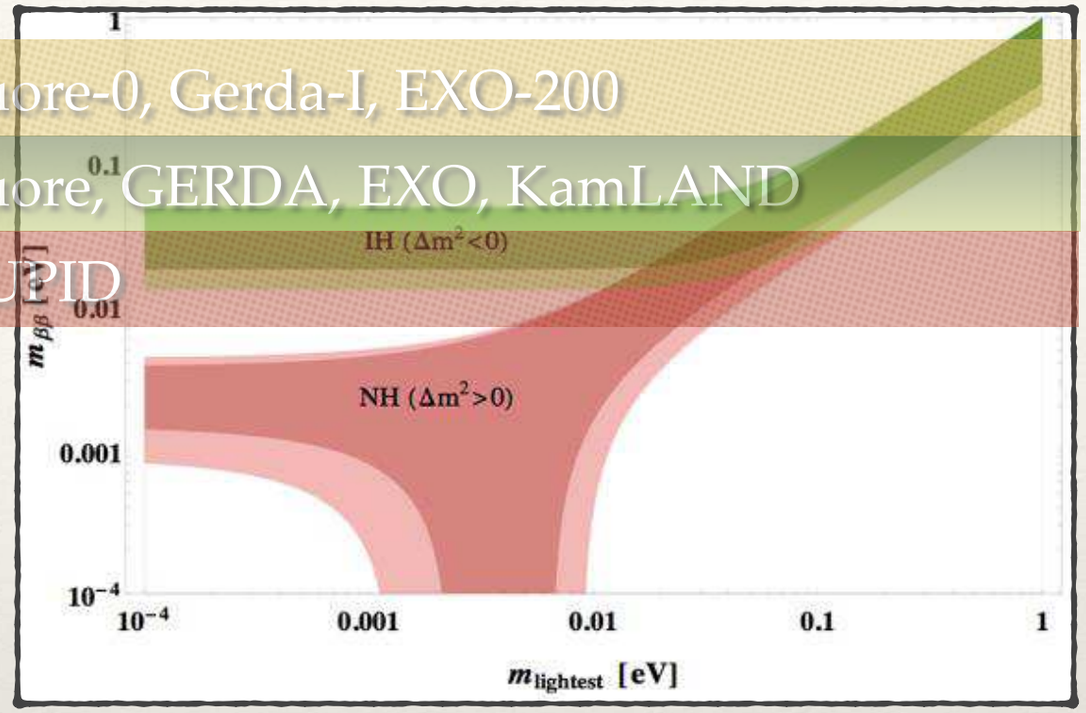
- Main effort today:
  - **CUORE** (~230 kg $^{130}TeO_2$ bolometers)
  - **GERDA-II** (~ 30 kg ^{76}Ge diodes)

Andrea Giuliani Review
Tuesday

- Long term plans:
  - R&D on bolometers
  - ^{76}Ge ? No program, as of today.

0νββ strategy

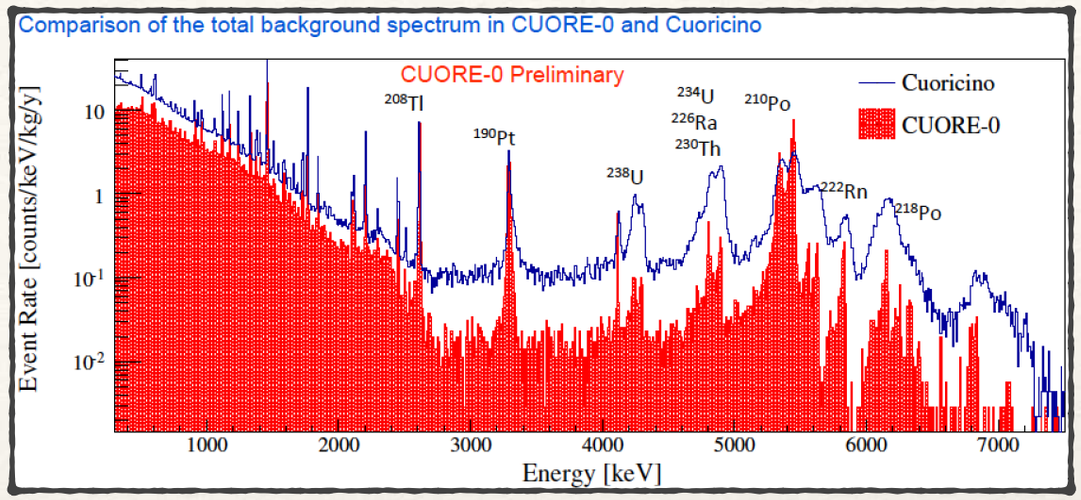
- **After CUORE and GERDA-II ?**
  - **CUORE** is ***background limited:*** simple mass scaling is useless and probably also very difficult to do
  - **GERDA** has lower background.
    - However: can we increase to ton scale ?
    - Not easily. Very expensive, and probably US based.



- **GOAL:** ***seek for a zero background experiment*** at **ton scale** to **explore inverse hierarchy region**
  - if g_a is not a show stopper

- **Answer: CUPID R&D**

The CUPID project (1)



- **CUPID: C**uore **U**pgrade with **P**article **Id**entification
  - Main goal: develop a **background free, high energy resolution, isotopically enriched** technology for Cuore upgrade
    - Build on our experience: bolometers with additional technology to reject residual α background (additional cleaning beyond Cuore-0 unlikely to be effective)
    - 130 signatures, 100 from CUORE, 30 non-CUORE members
    - International effort (8 countries)

See A. Giuliani's talk for details

1. arXiv:1504.03612 [pdf, other]
   R&D towards CUPID (CUORE Upgrade with Particle IDentification)
   The CUPID Interest Group
   Subjects: **Instrumentation and Detectors (physics.ins-det)**; High Energy Physics - Experiment (hep-ex); Nuclear Experiment (nucl-ex)
2. arXiv:1504.03599 [pdf, ps, other]
   CUPID: CUORE (Cryogenic Underground Observatory for Rare Events) Upgrade with Particle IDentification
   The CUPID Interest Group
   Subjects: **Instrumentation and Detectors (physics.ins-det)**; High Energy Physics - Experiment (hep-ex); Nuclear Experiment (nucl-ex)

Science: the Dark Universe

Neutrino Physics

Radiation from the Universe

Gravitational waves, Gravity and Quantum Physics

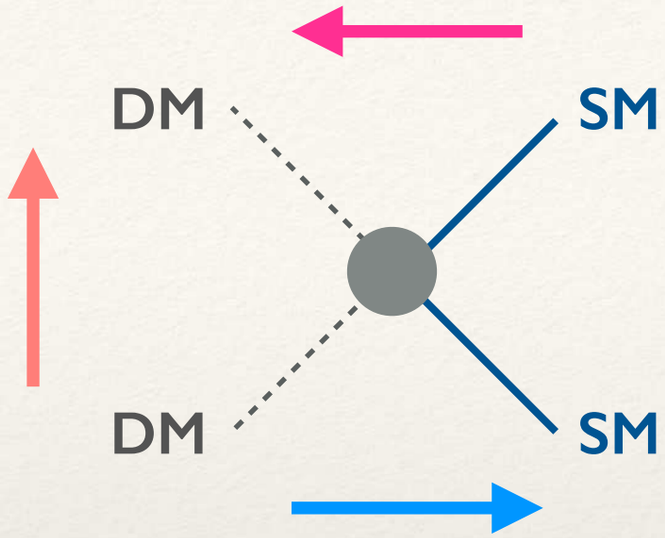
The Dark Universe

11 projects

COSMO_WNEXT
CRESST
DAMA-LIBRA
DARKSIDE
KWISP
MOSCAB (NEWS)
QUAX (SABRE)
XENON-1t

The Dark Universe: Dark Matter

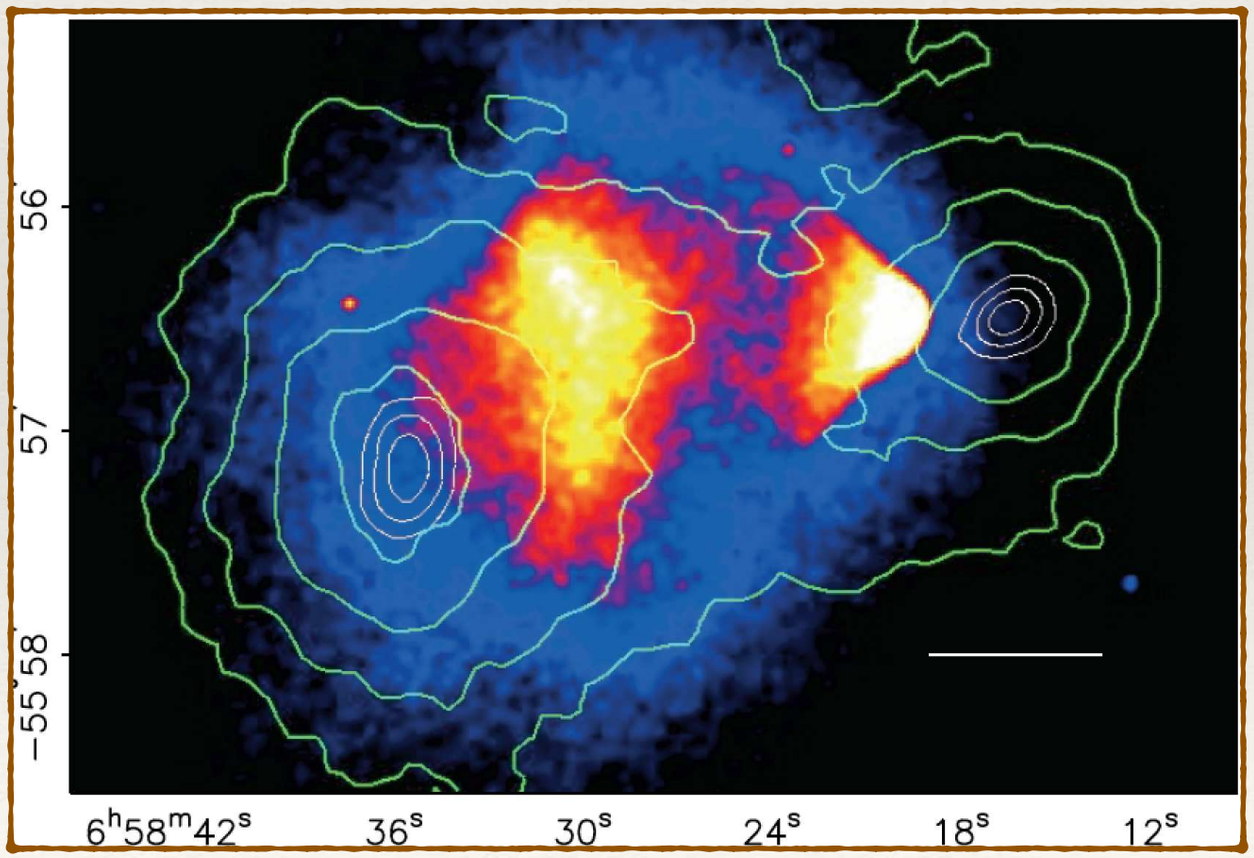
- **Three ways to Dark Matter**
  - **Direct**
  - **Indirect**
  - **Production (LHC)**



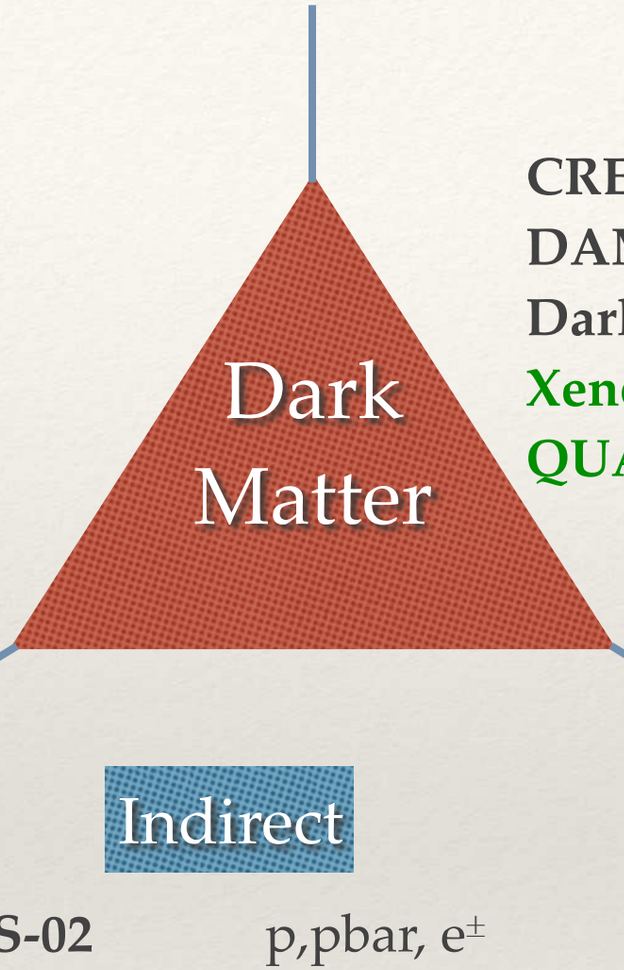
SM: Standard Model Particle

DM: Dark Matter Candidate

Unknown Interaction



Dark Matter search: aerial view



Production
@LHC or
Fixed Target
Experiments
(not my job…)

Mario Antonelli &
Tommaso Spadaio
Saturday

Direct Detection

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

New techniques R&D

CRESST2	**low mass WIMPs**
SABRE	**confirm Dama**
NEWS	**directionality**
MOSCAB	**new technology**

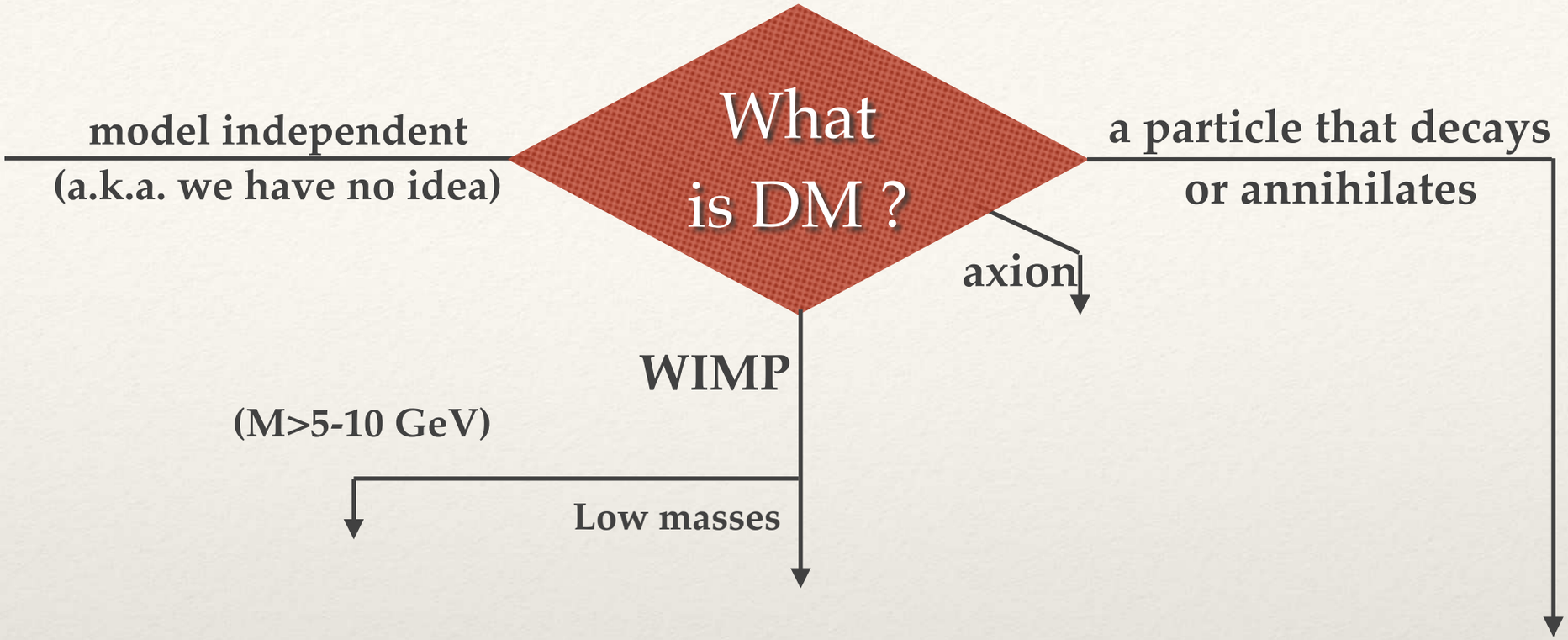
Indirect

AMS-02	p,pbar, $e^{\pm}$
Dampe	γ,p,pbar, $e^{\pm}$
Fermi	γ, $e^{\pm}$
Pamela	p,p,γ, $e^{\pm}$

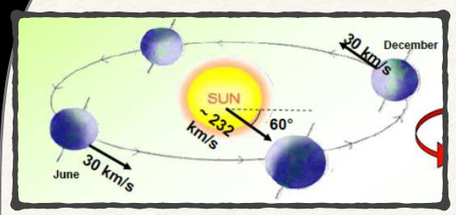
Gamma-400
killed by ROSCOSMOS

Running
Under construction
Future planning
Closing

Dark Matter: strategic flow



Dark Matter: strategic flow



Dama Libra

model independent
(a.k.a. we have no idea)

What is DM ?

a particle that decays or annihilates

Improve the signal

Confirm the signal

axion

QUAX

WIMP

Noble liquids (M>5-10 GeV)

Low masses

Direction and new techniques

DAMA Low Threshold

SABRE (@LNGS)

~100 kg

Xenon100

DarkSide-50kg

~1t scale

Xenon1t

~multi ton scale

XenonNt

DarkSide-20t

CRESST

CRESST2

NEWS

MOSCAB

Pamela

Fermi

AMS02

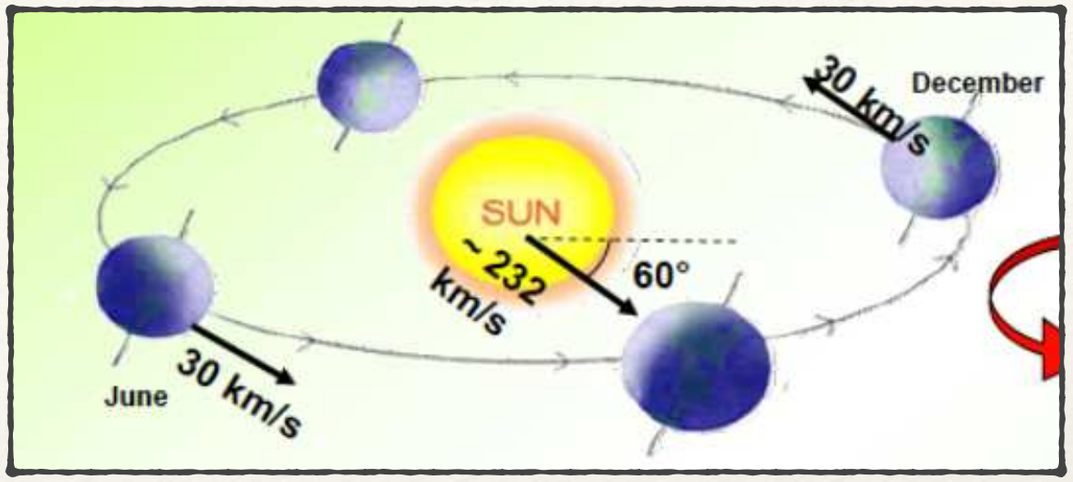
DAMPE

Exclude seasonal effects

SABRE (@Australia)

They will become experiments only if proved to be useful

Dama Libra

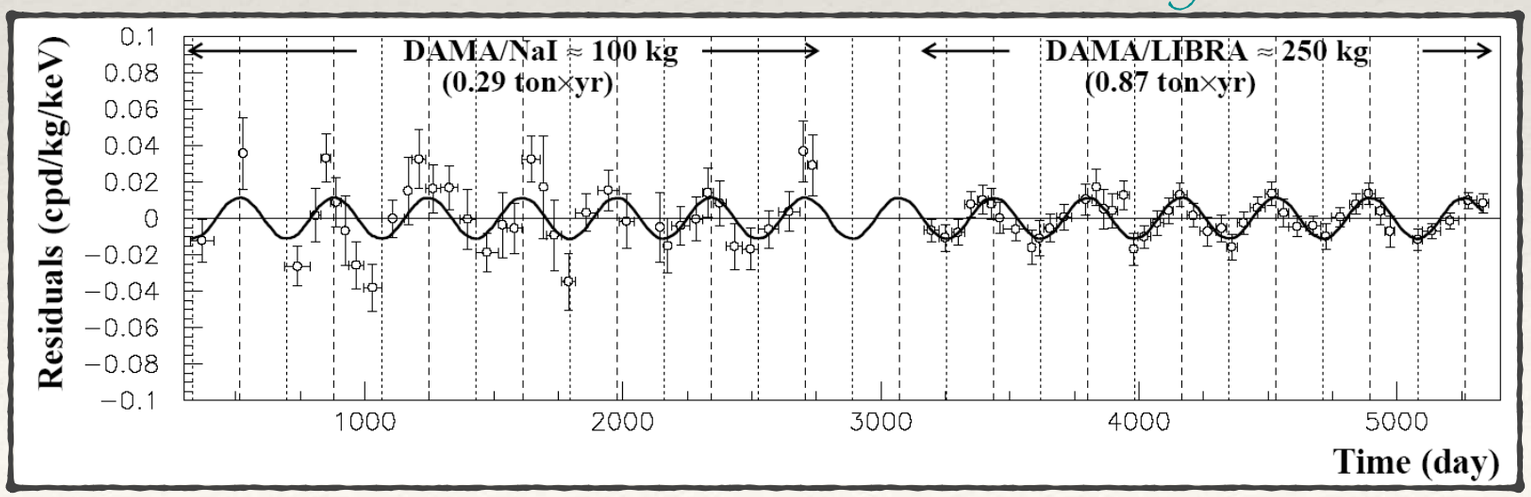


- **~250 kg NaI** scintillator crystals
  - **Low threshold** (2 keV published, 1 keV data taking in progress since 2011)
  - Long standing model independent signal
    - No credible interpretation beyond Dark Matter signature

BUT

- **Difficult to reconcile with other experiments assuming naïve WIMP** or simple electromagnetic interactions (LUX, Xenon-100 2015)

See Rita Bernabei on Thursday



R&D for SABRE

- **S**odium Iodide with **A**ctive **B**ackground **Re**jection
  - A low background NaI detector to **test Dama-Libra at LNGS and Australia**
  - Activity started at Princeton in 2010 (EAGER Grant Calaprice-Wright)
    - Selection of clean powder
    - Purification of the powder
    - Growth of 5 kg crystals
  - Main goal: low ^{40}K + (^{87}Rb and ^{210}Pb)
- **NOTE: a group of young INFN collaborators**
  - Good thing, but they will need time.
  - **It is Not** an easy business

Crystal Growth Facility

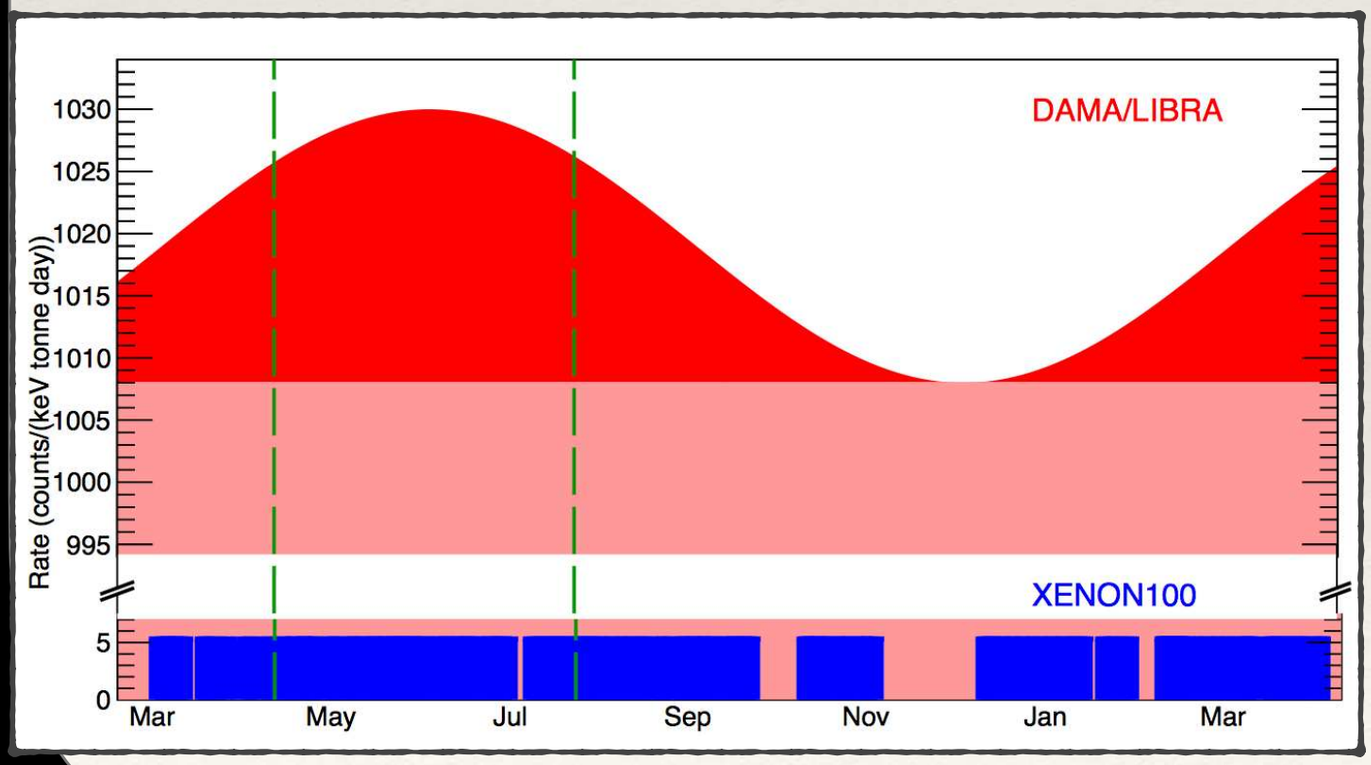
Xenon-100 results

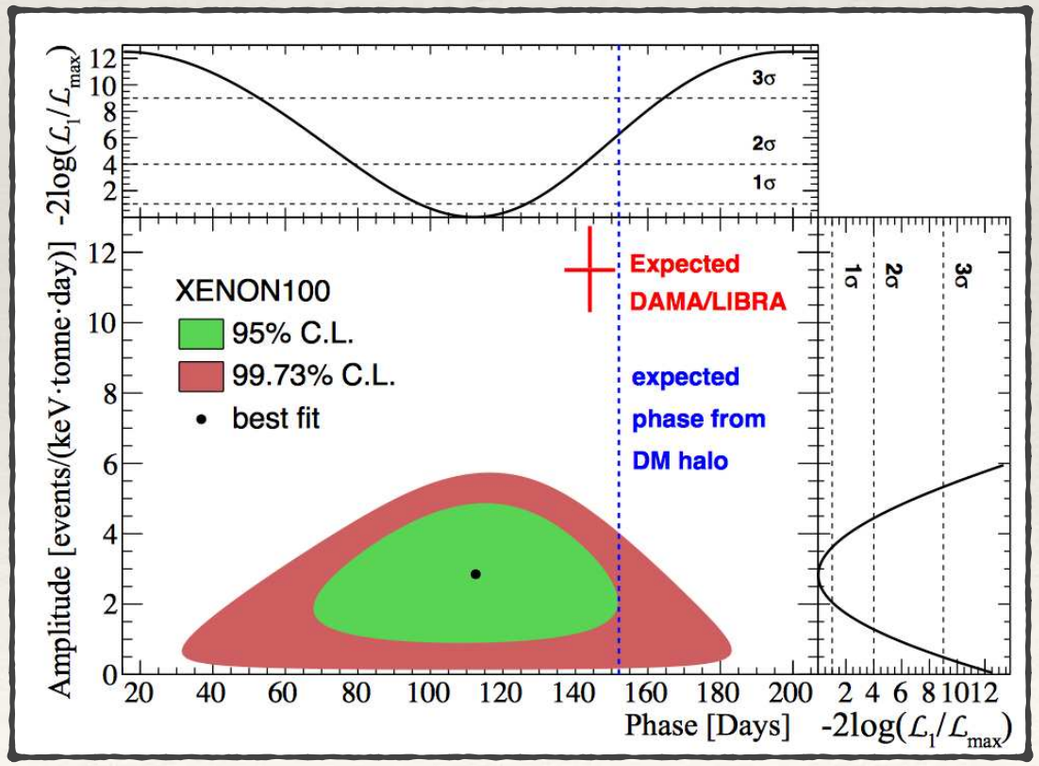
- Two major results in 2015

See Elena Aprile on Thursday

Exclusion of Leptophilic Dark Matter Models using XENON100 Electronic Recoil Data
Science 2015 vol. 349 no. 6250 pp. 851-854

Search for Event Rate Modulation in XENON100 Electronic Recoil Data
Phys.Rev.Lett. 115 (2015) 9, 091302





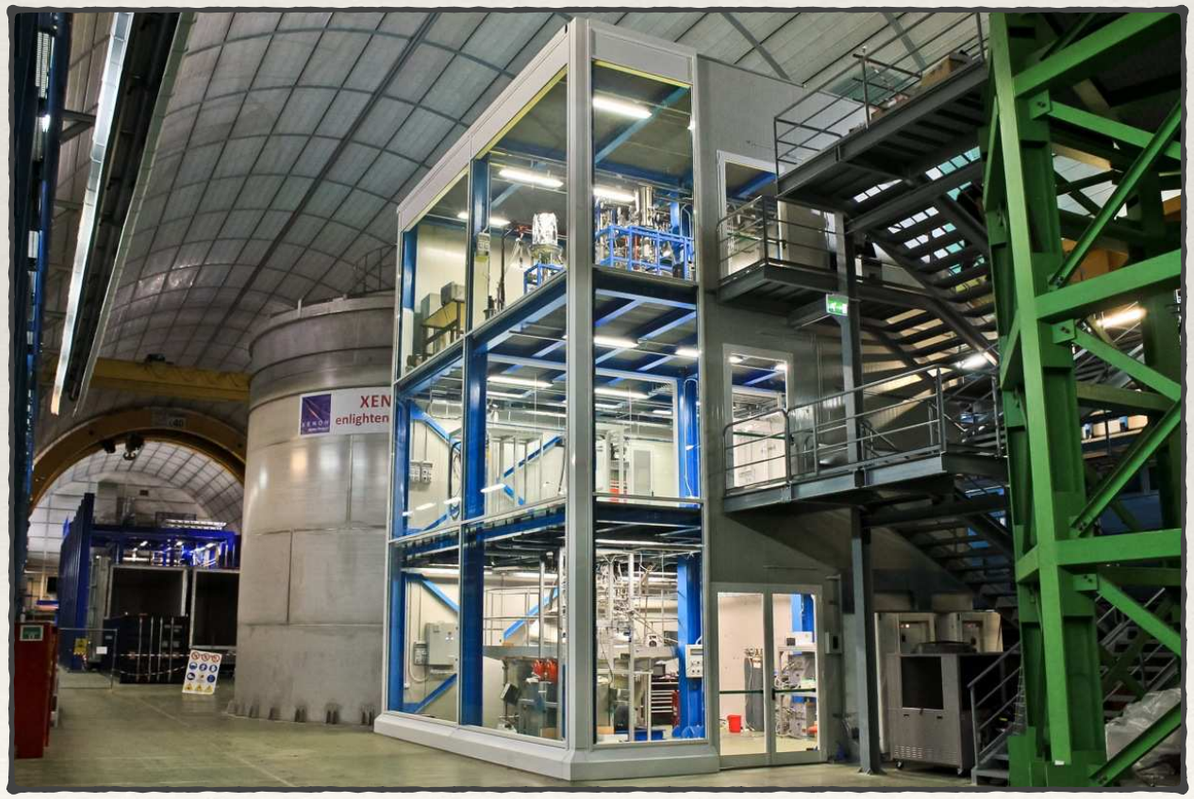
Xenon 1t: almost ready to go

- Construction close to completion

See Elena Aprile on Thursday

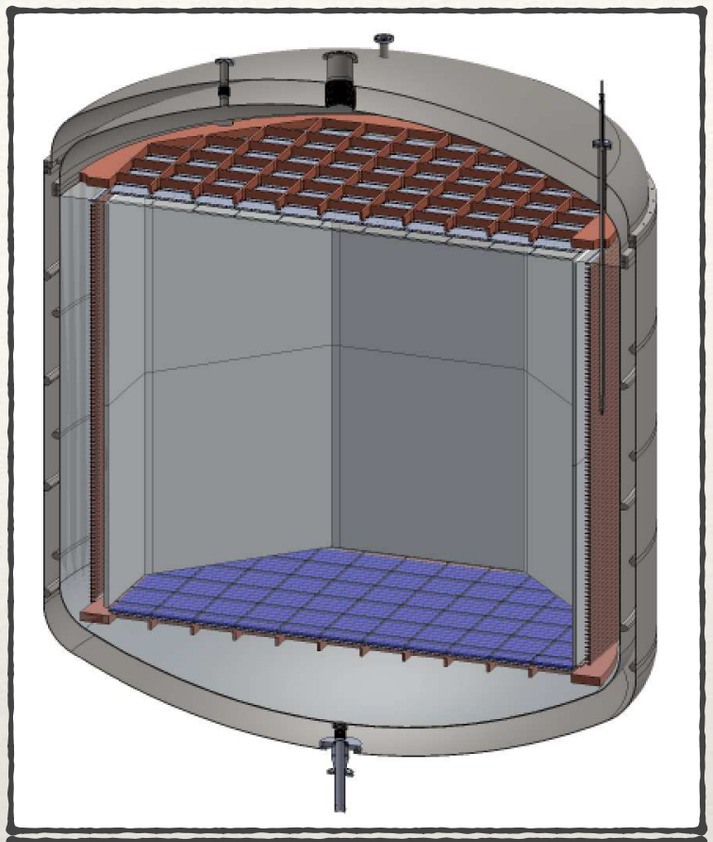
  - Kick-off meeting: **Nov. 11th, 2015, filling in progress**
  - Physics in 2016. **Expected D.M. results in 2017.**
    - **Multi-ton proposal expected**

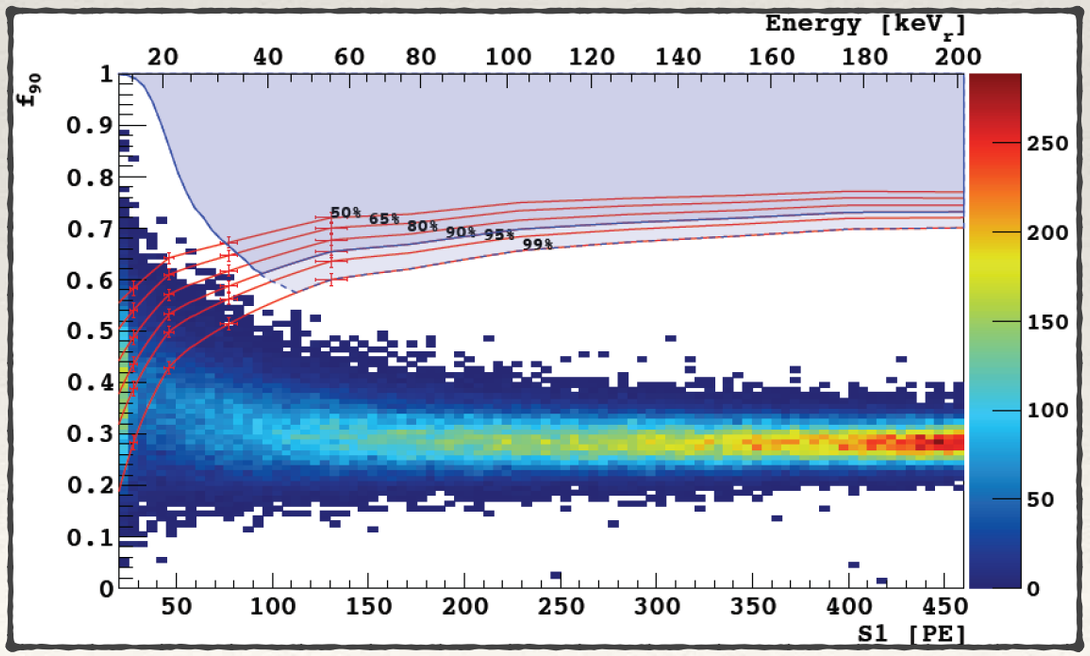
Tank and Building in Hall B



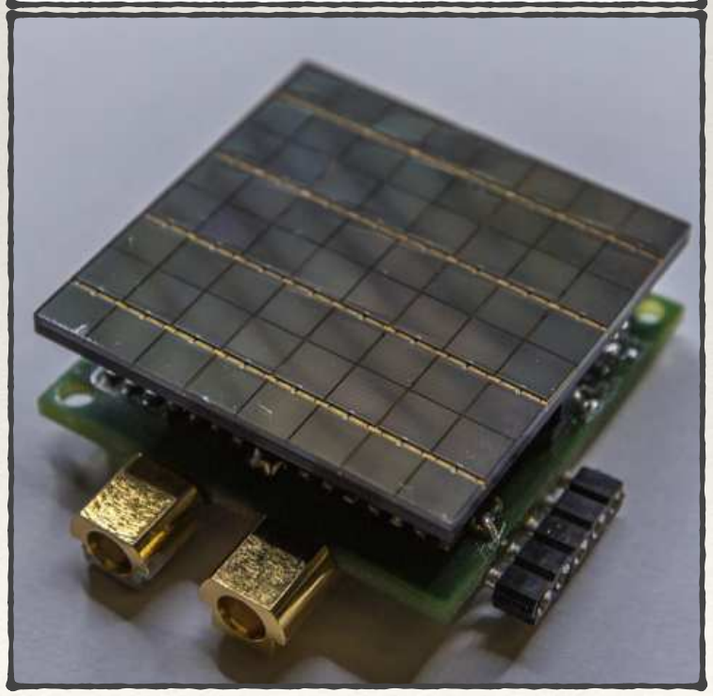
Darkside-50 kg (future 20t)

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





SiPM device under development at FBK (INFN Trento)



Low ^{39}Ar Argon

- A key point for LAr D.M. detector is to keep the **^{39}Ar** background low

- **DarkSide-50. Two steps:**
  - 1) Underground Argon with ***intrinsically low ^{39}Ar content***
  - 2) Pulse-Shape discrimination

- **DarkSide-20t**
  - **DarkSide-50 approach insufficient.** ***A further reduction is needed.***
  - Solution: ***isotopic enrichment by distillation***
    - **URANIA and ARIA projects**

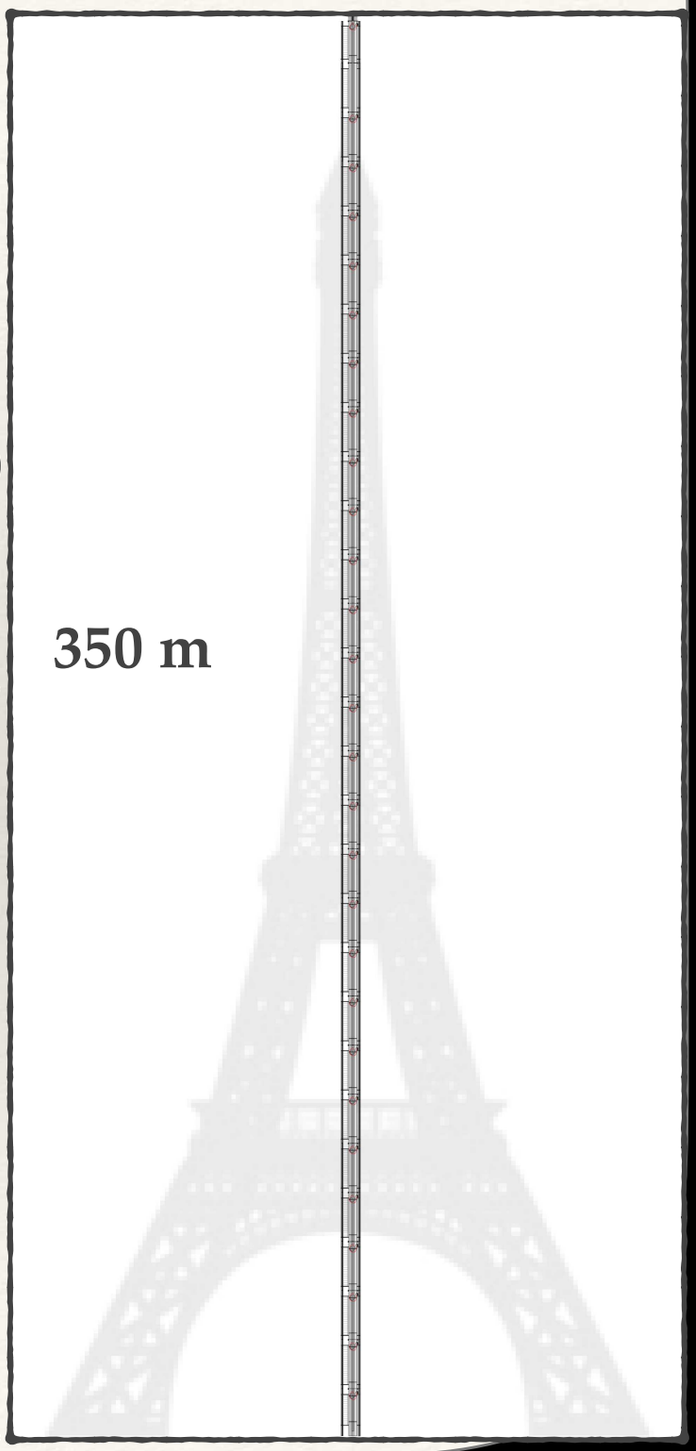
ARIA project in Sardinia

- Seruci **cryogenic distillation column**
  - Dark Matter goal: **separate by distillation ^{40}Ar**
  - Potential by-product
    - **Unique plant for isotope enrichment**
    - **^{13}C, ^{15}N, ^{18}O** and others (Industry, Medical, **0νββ?**)

Seruci Mine in Sardinia

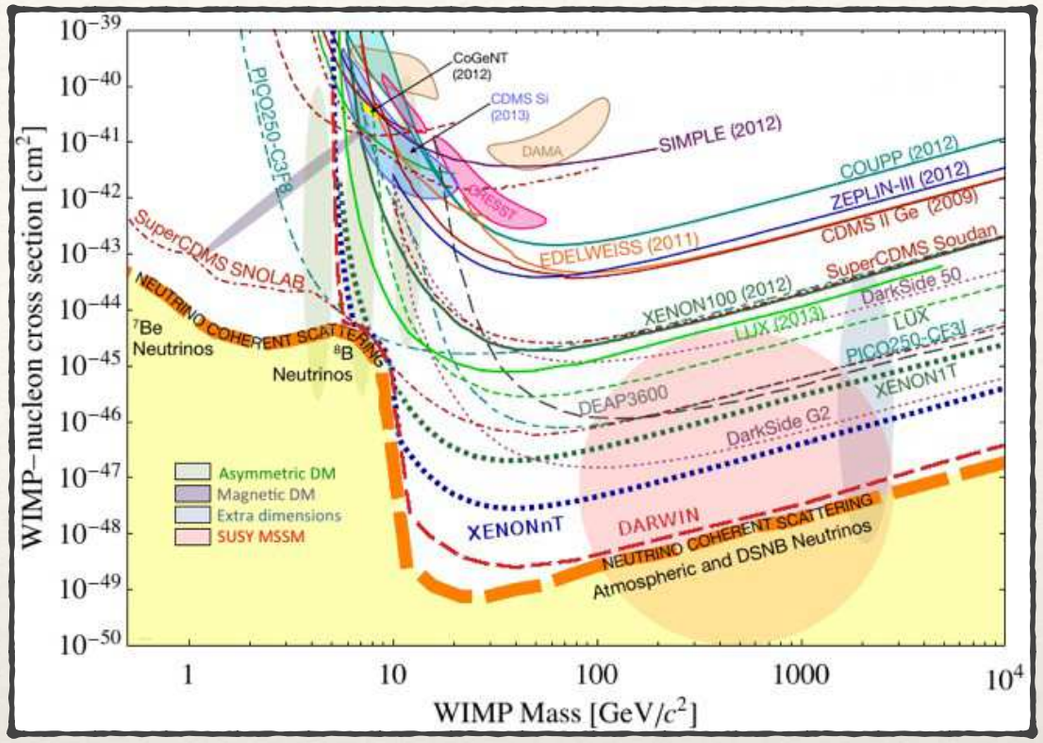
Existing shaft N. 1

Size comparison



DM search summary

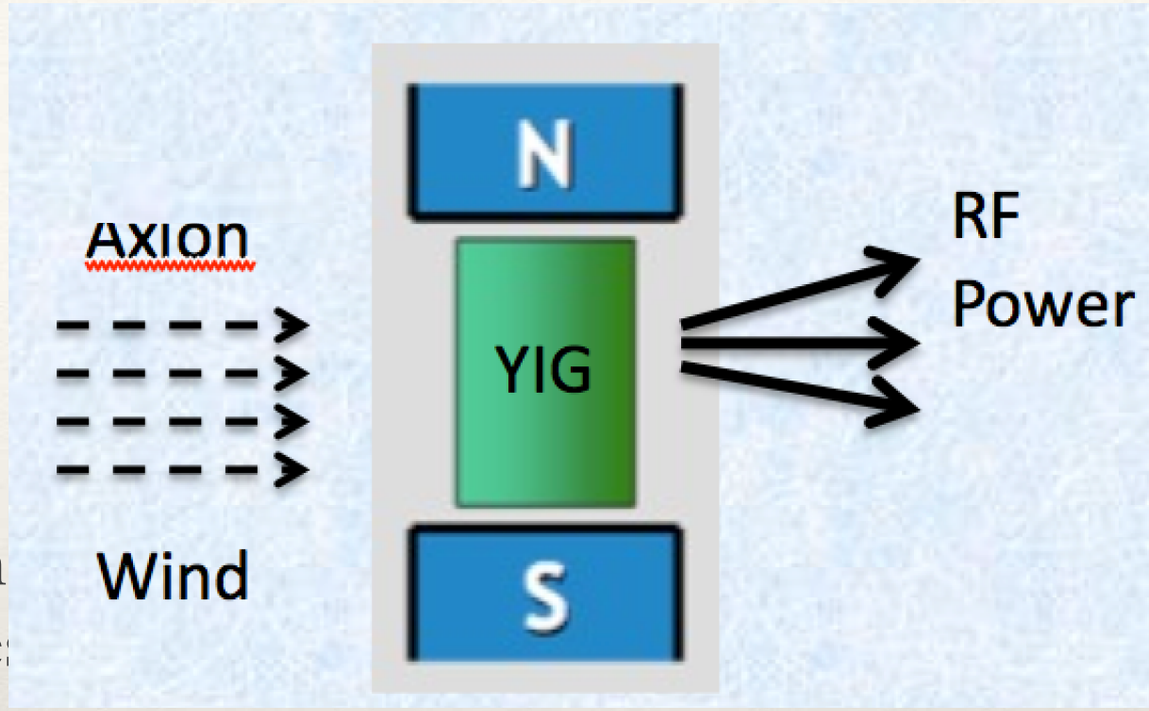
- Goals:
  - 1) Confirm Dama-Libra signal
    - Dama-Libra upgrade ? Depending on Dama-Libra low threshold results and possibility to learn more about the candidate
    - SABRE for confirmation (long term effort)



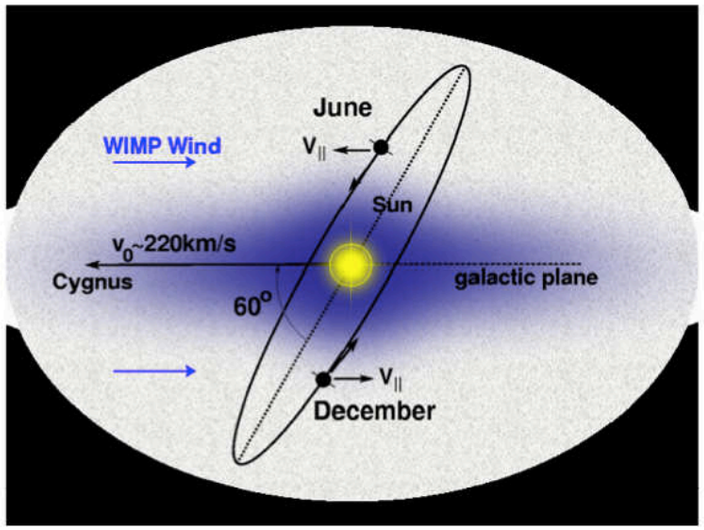
- 2) Start a program for reaching ultimate sensitivity (neutrino limited) with noble liquid detectors
  - Xenon-nT and Darkside-20t will be the main effort
- 3) Develop, if possibile, innovative techniques for directionality

QUAX: search for axions

- **Main idea:**
  - Use axion spin coupling
  - The axion field may act as an effective magnetic field on electron spin
  - It may induce ferromagnetic transition in magnetised sample and emit μ-waves



- R&D is in progress 2015-2016
  - Noise budget unknown
  - Collaboration with INRIM
  - Magnet uniformity and stability: a challenge
  - Group: PD, LNL, TO



Directionality between axion wind and spin

Science: radiation from the Universe

Neutrino Physics

Radiation from the Universe

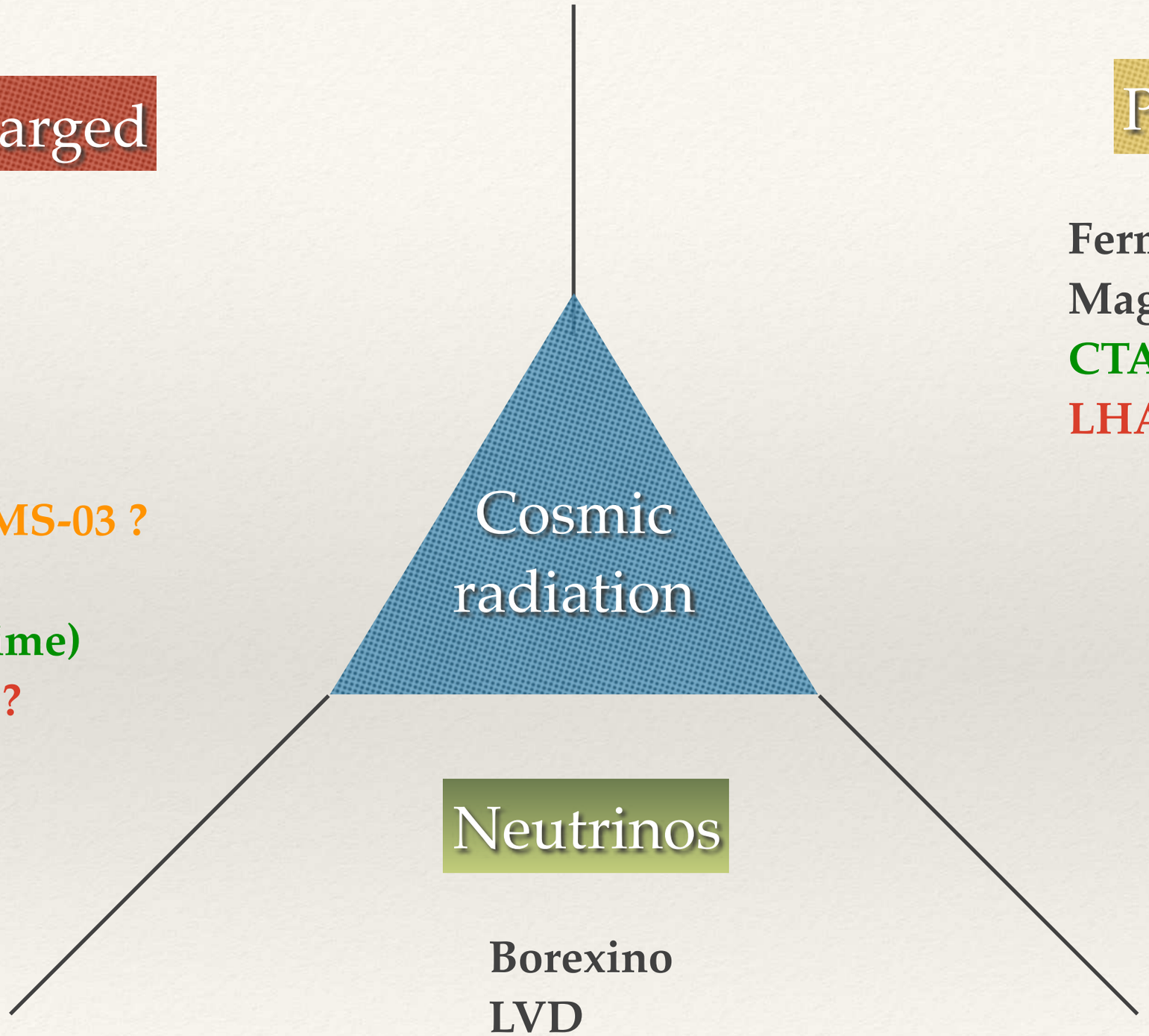
13 projects

AMS02
AUGER
CTA
DAMPE
FERMI
GAMMA-400
JEM-EUSO
KM3
(LHAASO)
LSPE
LVD
MAGIC
PAMELA-WIZARD

Gravitational waves, Gravity and Quantum Physics

The Dark Universe

Cosmic radiation: aerial view



Charged

Pamela
AMS-02
Dampe

Herd ? AMS-03 ?

Auger (Prime)
LHAASO ?

Photons

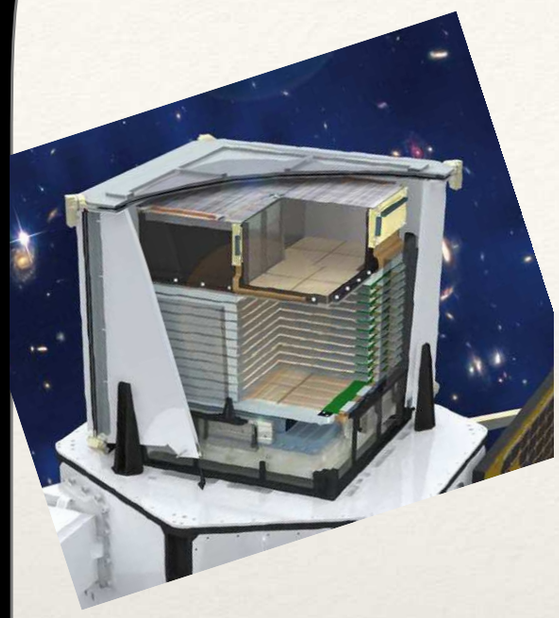
Fermi
Magic
CTA
LHAASO ?

Neutrinos

Borexino
LVD
Km3Net

Running
Under construction
Future planning
Closing

Flying detectors



AGILE, 23-4-2006
Mainly X and γ

Marco Tavani
on Tuesday

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

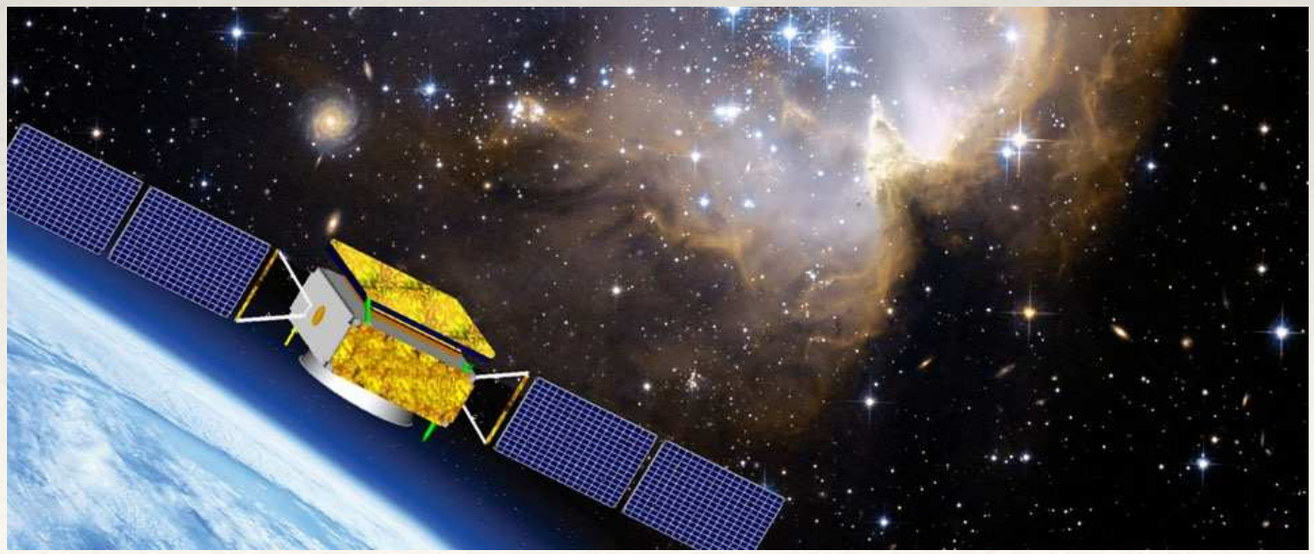
Piergiorgio
Picozza
on Wednesday

Luca Latronico
on Tuesday

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

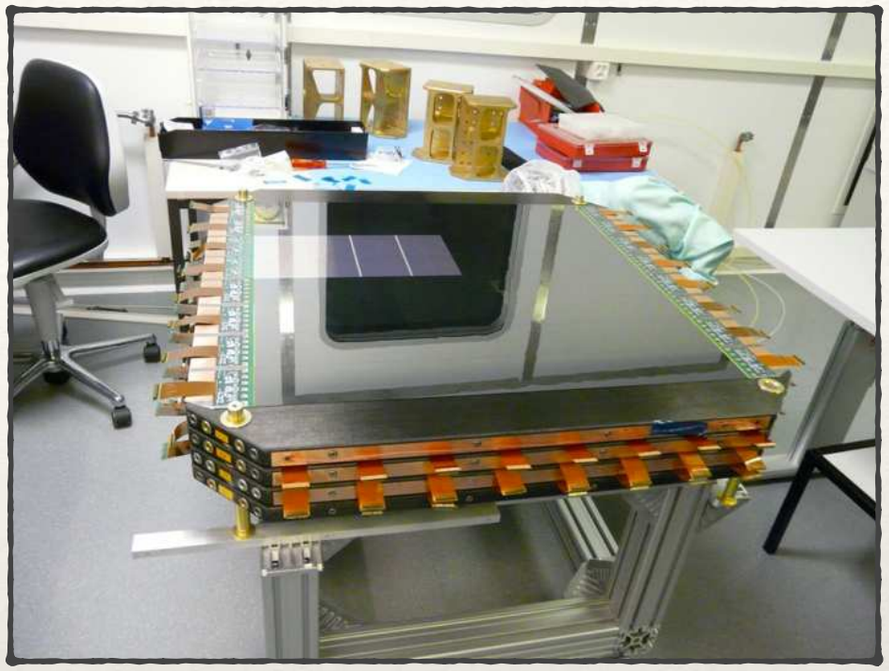
AMS-02, 11-6-2011
Charged particles
up to 1 TeV

DAMPE, 17-12-2015
Dark Matter Explorer



Space detectors

- Last Born: **Dampe** (China)
  - Important synergy with CAS. Chinese fundings.
  - 2 GeV - 10 TeV e/γ 30 GeV - 100 TeV CR
  - Launched Dec.17 2015
- Gamma-400
  - Very unfortunately killed by ROSCOSMOS



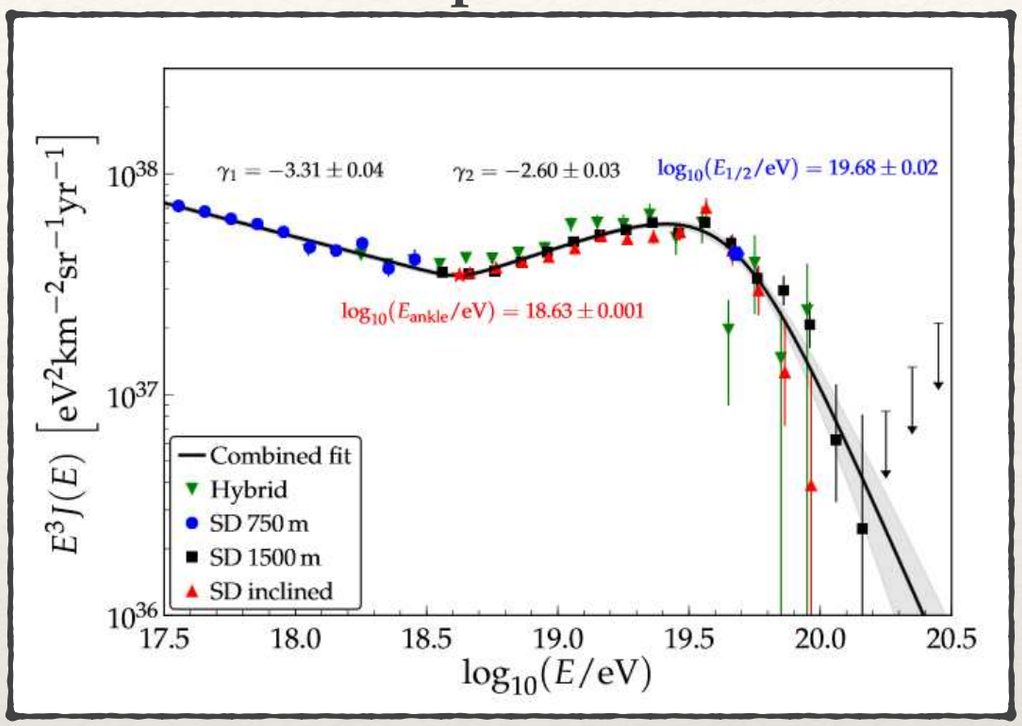
- The future (under discussion, no approvals yet)
  - **HERD**: R&D just started. Circa 2022. Non-magnetic tracker + Calocube
  - **XPE**: X ray polarimetry. Mostly astrophysics, but with a crucial hardware contribution on the instrument (INFN Pisa)
  - Small participation to **GAPS** (anti-neutron balloon detector)
  - R&D for long term missions (M5 ESA)
  - **Discovery of GW makes continuation of FERMI mandatory**

Piera Ghia
Antonella Castellina
on Thursday

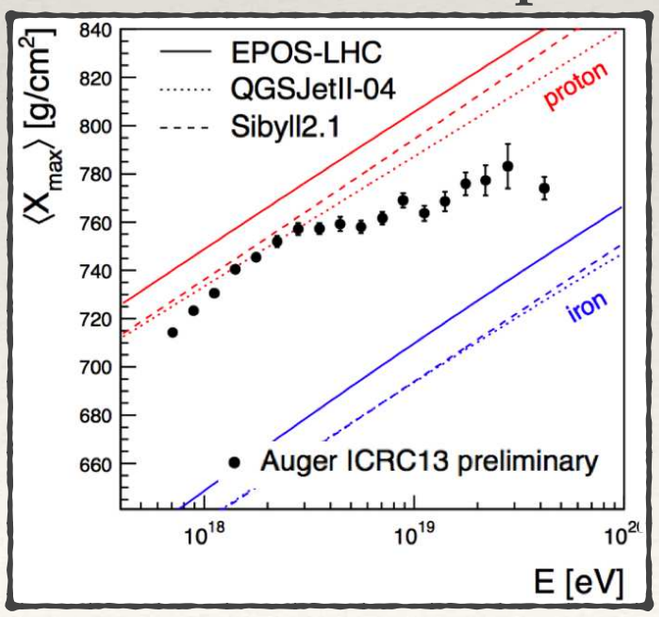
Auger (Prime)

- **AUGER** main result: **GZK works. Or not ?**
  - GZK or end of spectrum (maybe GZK in the sources)?
  - Heavy composition or systematics or new physics ?
  - Can we detect GZK photons ?
- Hardware upgrade to improve muon detection

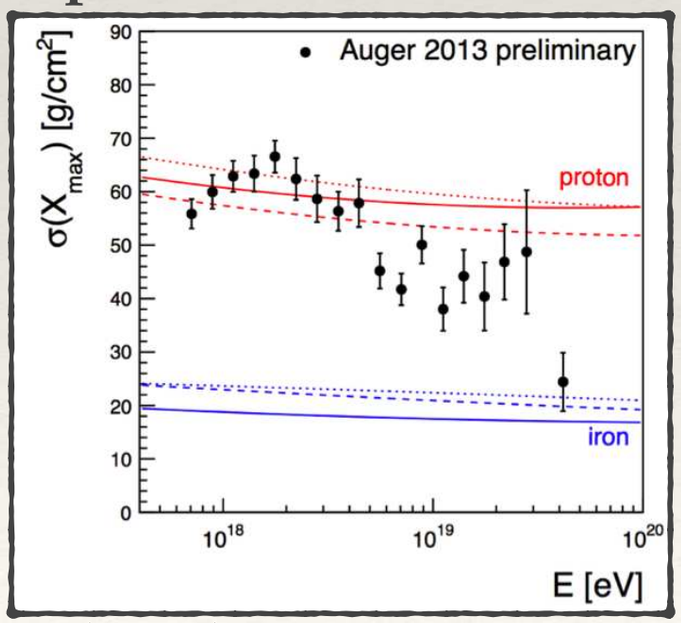
spectrum



composition puzzle

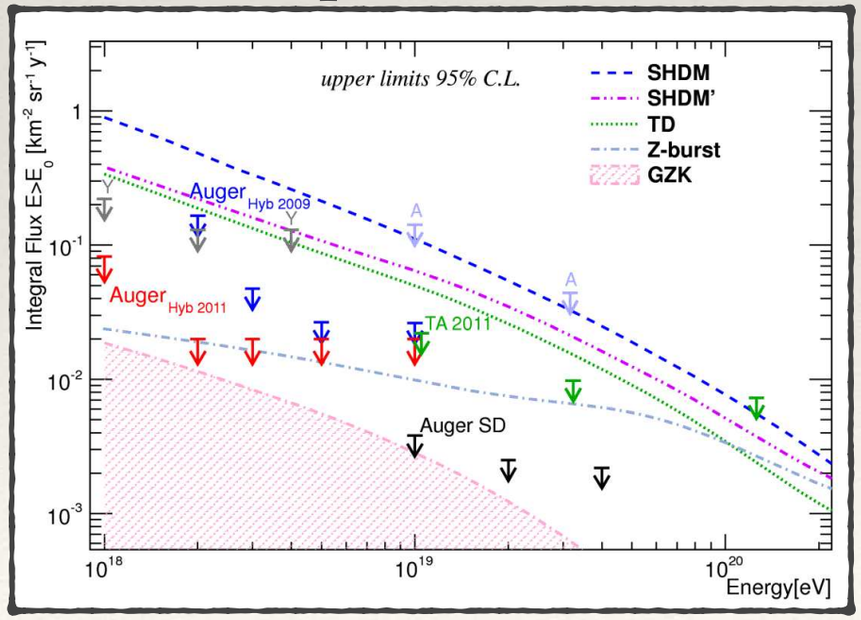


X_{max}



$\sigma(X_{max})$

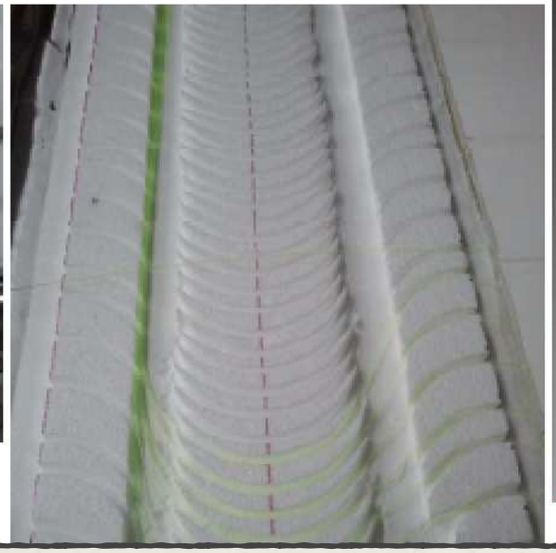
photons

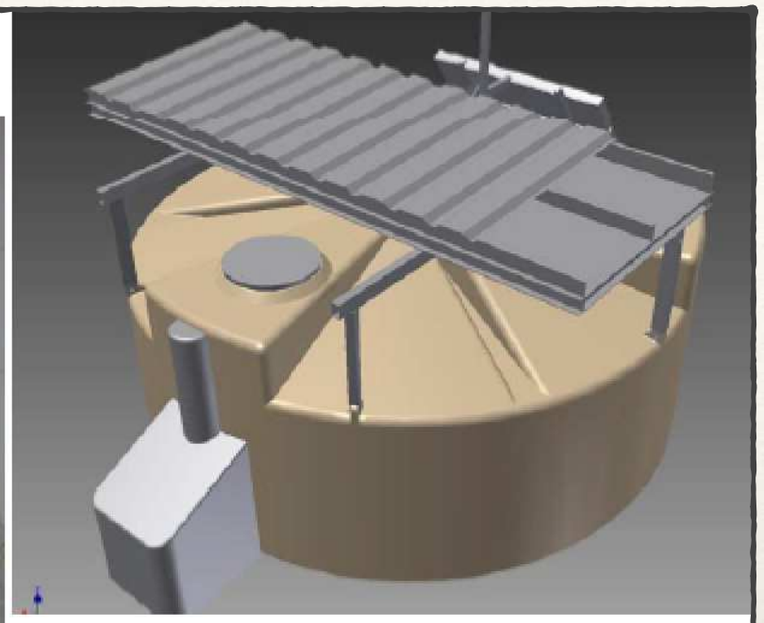


GZK near ?

Auger Prime

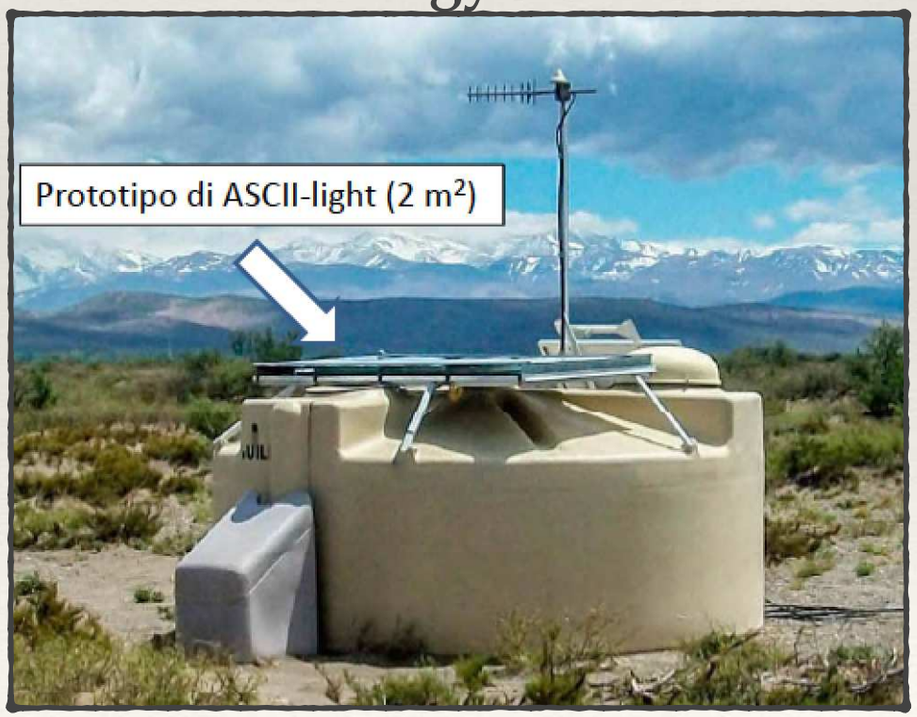
Prototype done in Torino





- **CSN2 has approved the upgrade**
- **However:**
  - International cost sharing almost clear
  - INFN approved, although final funding level to be matched with international contribution
    - 11% is maximum INFN share
  - 10 y approval signed

Technology chosen: ASCII



Zhen Cao
on Wednesday

LHAASO ?

- Bridging direct space measurement with large ground based detectors

- **Goal 1: CRs around and above the knee 10^{12} - 10^{18} eV**
  - Understanding knee origin and disentangle galactic and possible extragalactic components
  - Composition around the knee is not understood completely, spectral index Z dependent
    - Simple diffusion models are challenged by data, and anisotropies are important

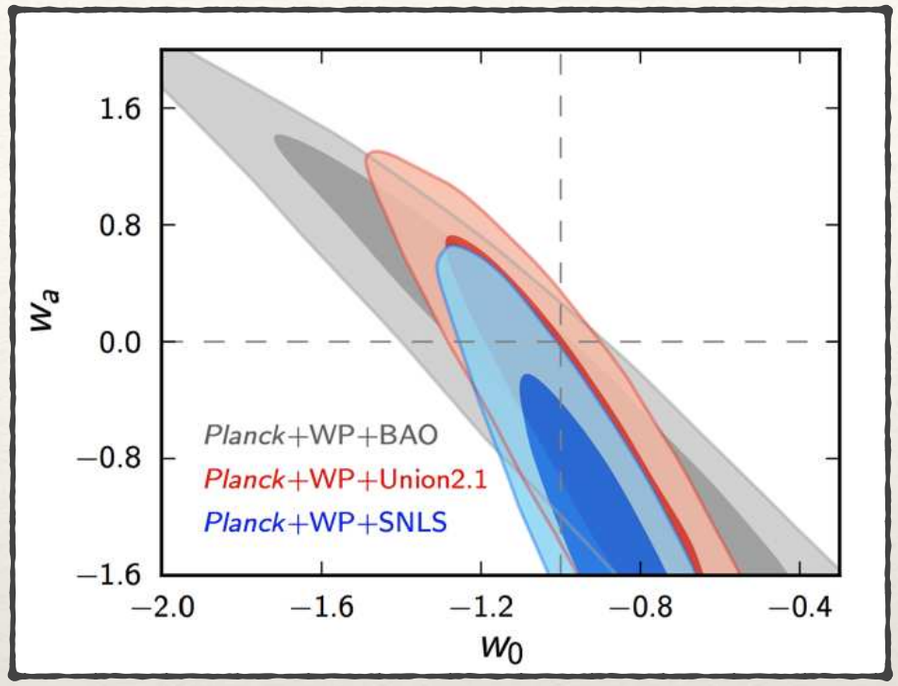
- **Goal 2: photons 10^{11} - 10^{15} eV**
  - Better or complementary to CTA for transients, GRB, all sky surveys, diffuse signal
  - Searching for PeVatrons (hot topic after PeV neutrino discovery)

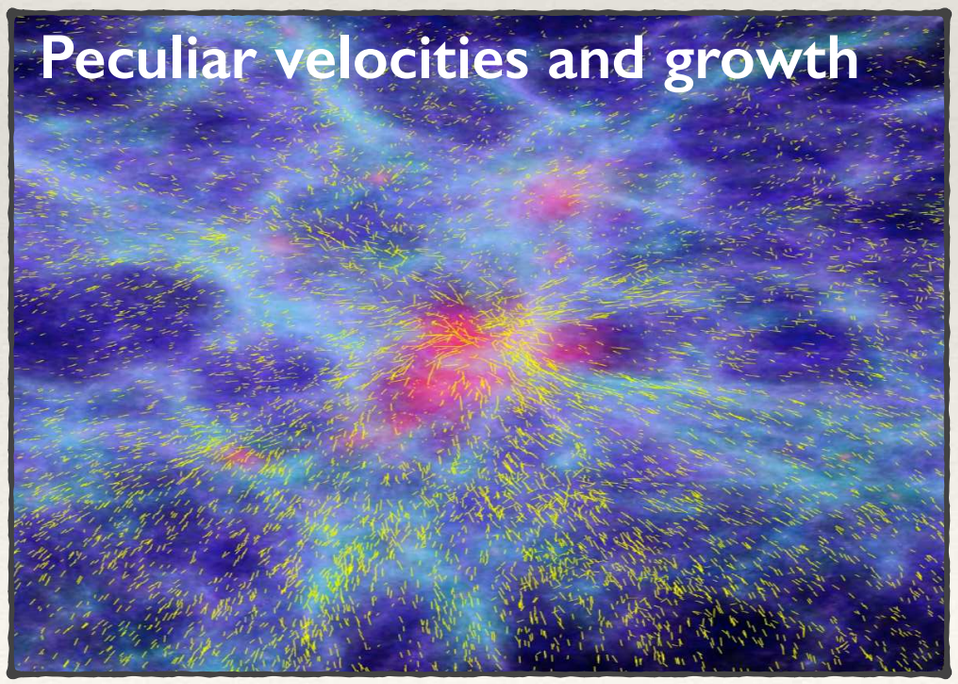
EUCLID: study of dark energy

- **EUCLID:** mapping the universe with sufficient precision to disentangle different dark energy models (and much more)
  - High precision Barionic Acoustic Oscillations
  - High precision weak gravitational lensing
  - Measure the growth of structures
  - Launch: ~ 2021

- **One of the main fundamental scientific questions for the next decades**
  - INFN should indeed play a role!
    - An exploratory group in place (PD and BO so far, 20 people)
    - More people welcome !

$w(a) = w_0 + w_a (1 - a)$



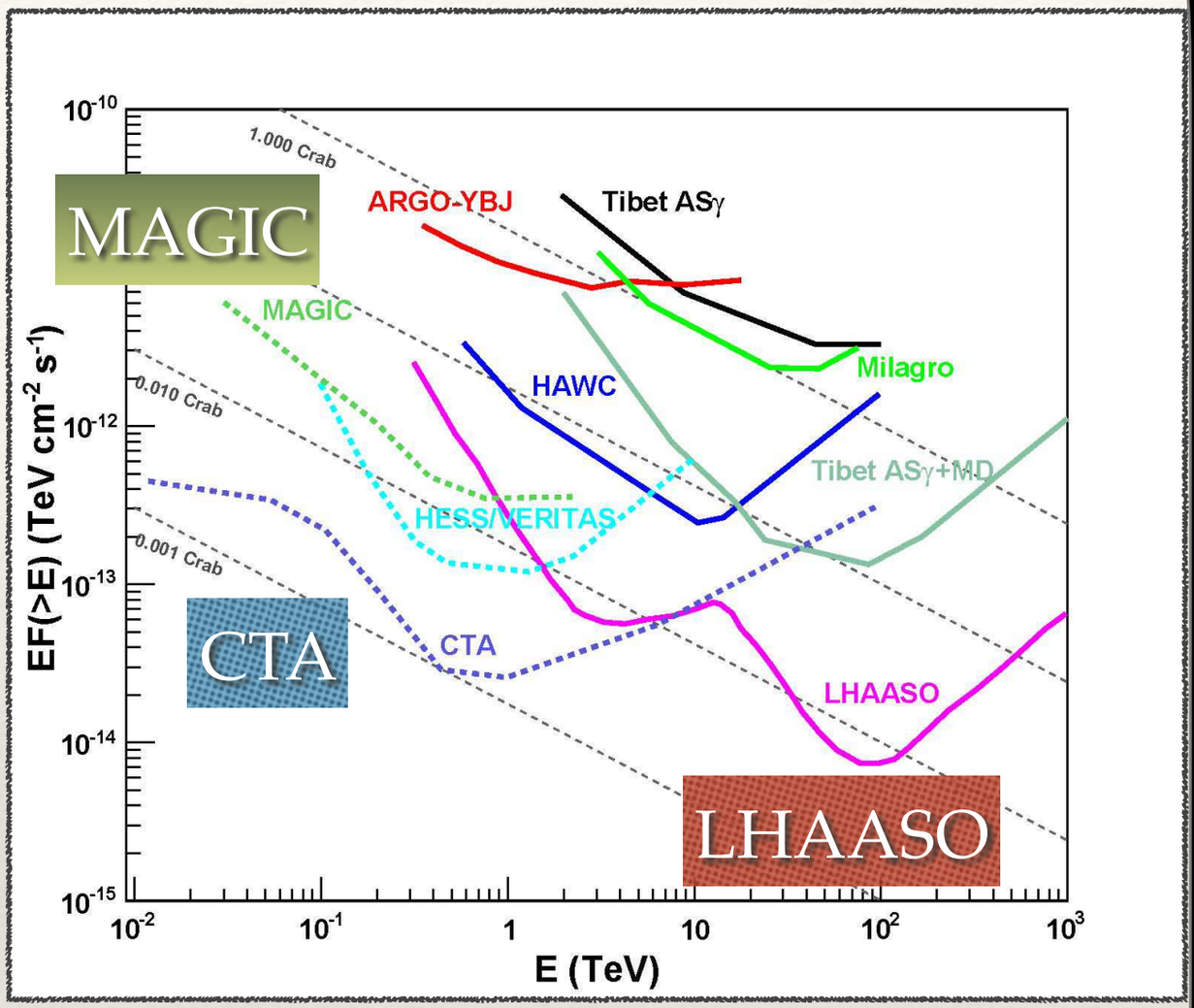


From Magic to CTA

- **Magic** with **2 large Ch mirrors**
  - Reduced threshold down to 30 GeV
  - Most distant γ source ever observed
  - Gravitational lensing with H.E. γ
- **CTA, a Global project**
  - Pointing observatory 50 GeV-100 TeV
  - Large Italian effort INAF + INFN
  - INFN joined GmbH and signed EoI
  - Main INFN scopes:
    - LT trigger & electronics
    - SiPM for ST
    - Computing and data management
- **Chile** and **Canaries** sites **selected**
- Good synergy with ESO and MAGIC sites

High Energy γs from ground

- **MAGIC**
  - **Running,** recently improved trigger, threshold down to 35 GeV
  - INFN support till beginning of CTA
- **CTA** Masahiro Teshima Tuesday
  - Pointing observatory 100 GeV - 100 TeV
  - Coordination with INAF
  - INFN scope: trigger, electronics for LT
  - Building on MAGIC experience: **Canary Islands site approved besides Chile !**
- **LHAASO**
  - **Large FoV and duty cycle.** More sensitivity above 10 TeV and knee CR physics too
  - Complementary with CTA with better sensitivity at high energy and transient detection capability
  - Scope: physics, simulations, analysis: **building on ARGO experience**

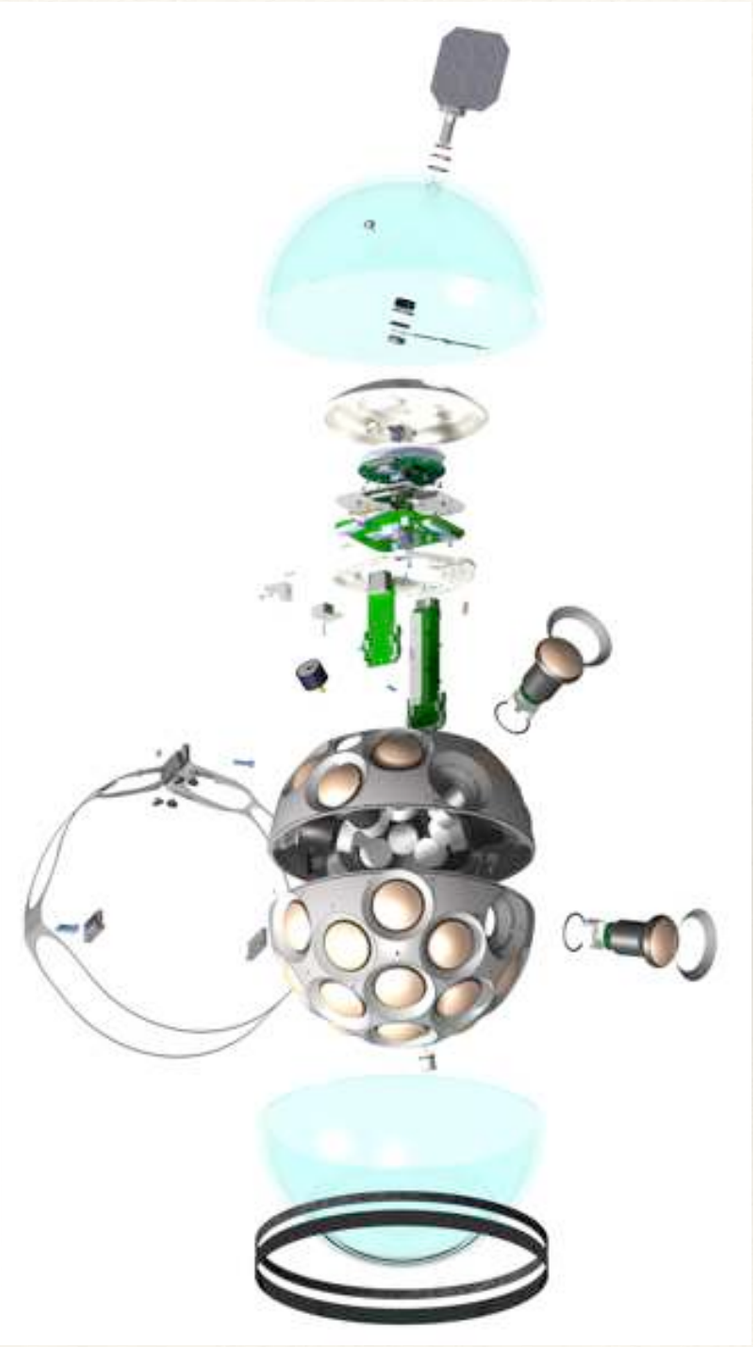


Paolo Piattelli

Tomorrow

High energy neutrinos

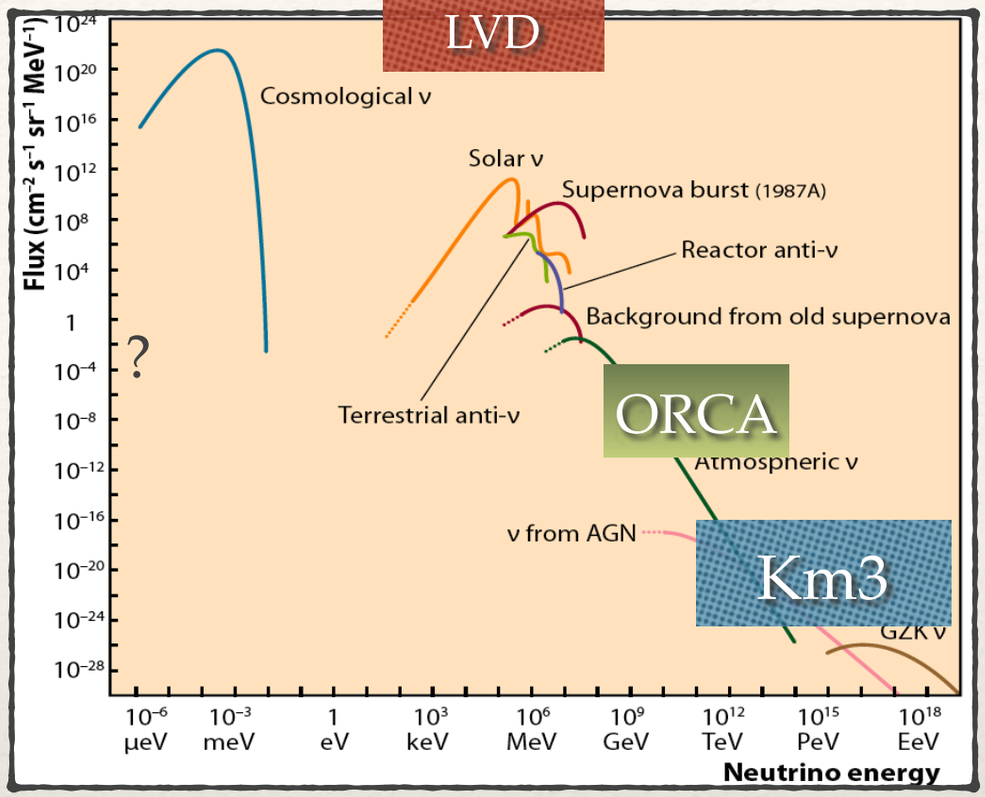
- After **Ice Cube discovery,** increased interest for a high energy neutrino observatory in the Mediterranean
  - Water has better angular resolution w.r.t. ice, a key feature to discover sources
  - **24 M€** investment close to completion.
  - **8 towers and 24 strings will be deployed in water in 2015/2016/2017**
  - 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 and from other European countries



Paolo Piattelli
Tomorrow

High energy neutrinos

- **Deep sea detectors for:**
  - Neutrino astronomy in the Mediterranean: **Km3Net (Sicily)**
  - Atmospheric neutrinos (hierarchy): **ORCA (Toulon)**
- Both **high priority,** but only **partially funded**
  - Work in progress
  - **2 strings and 1 tower deployed a few days ago!**

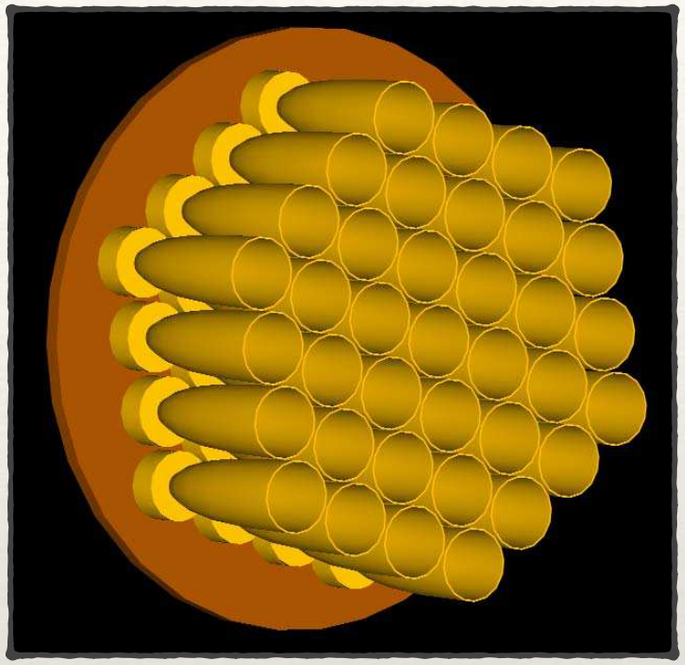


Tower

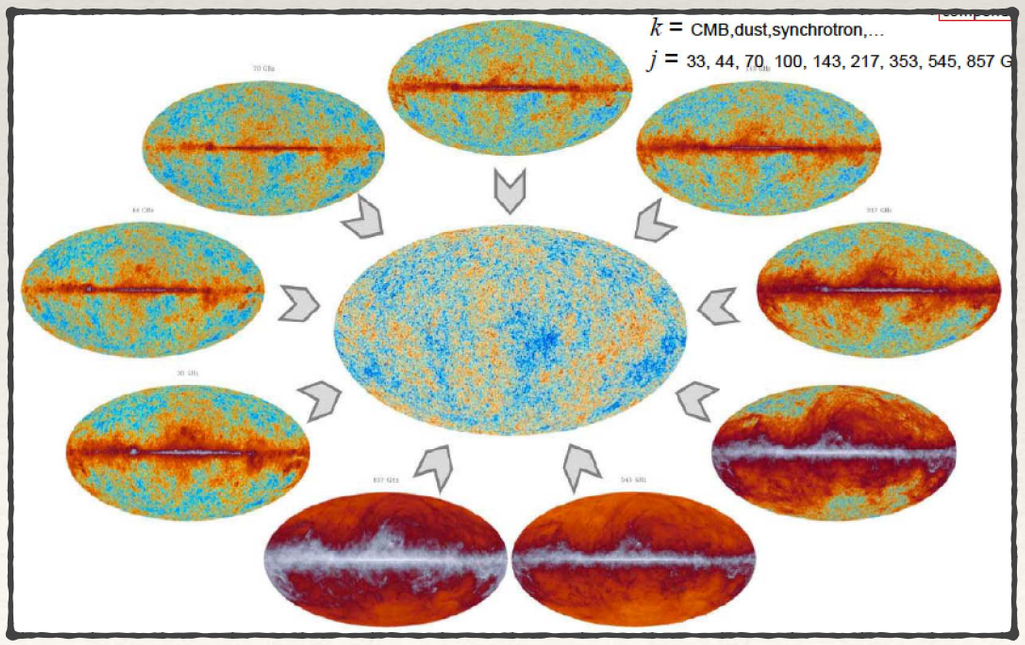
LSPE: PROBING COSMIC INFLATION

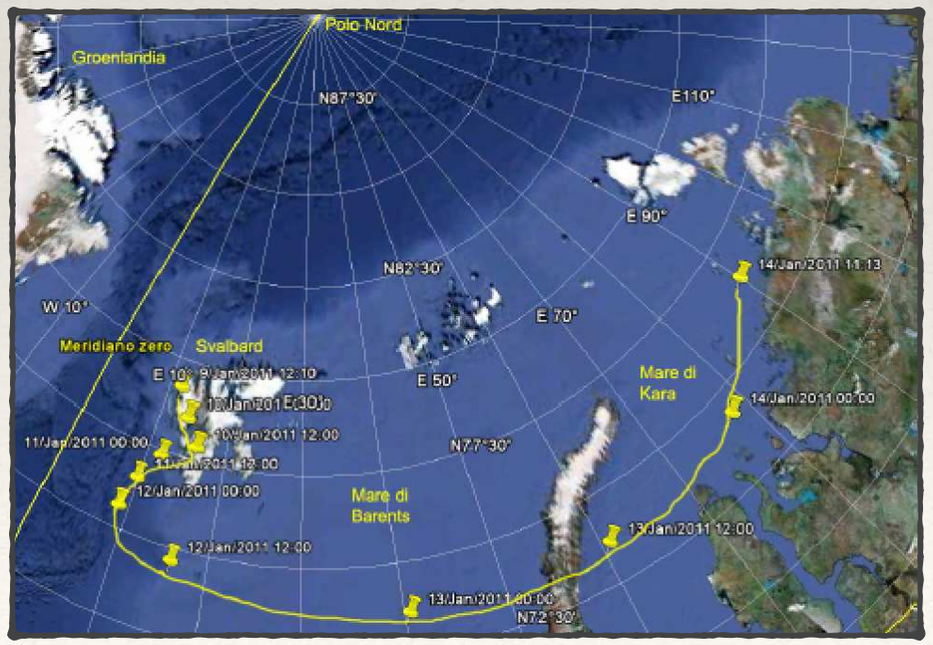
P. De Bernardis
A. Baldini, F. Gatti

- **LSPE: Large Scale Polarisation Explorer**
  - Balloon mission for polarised CMB photons
  - Search for B-modes in a **multi-wavelength approach**
  - Re-use of technology R&D for neutrino mass measurement (**μ-bolometers**) **+ TES + KIDs**
    - **5 channels** (**40 - 250 GHz**) **on spinning payload**



- **Angular resol. 1.5°-2.3° Sky coverage: 20-25%**
- **Sensitivity: about 10 μK**





Summary on cosmic radiation

- Important past investments have paid off (and still are)
  - AMS-02, FERMI will continue for several years
  - AUGER will be upgraded and continued for 10 years

- After discovery of GW, multi-messenger observatories are crucial, particularly for photons and neutrinos

- Path from MAGIC to CTA agreed

- Path to neutrino astronomy clear but still unfunded. A high scientific priority still lacking resources

- Discussion in progress for:
  - LHAASO: interesting in principle, but funding problem and very weak collaboration
  - Future space missions: situation still unclear; discussion in progress in the community

Science: Gravitational Waves, Gravity and Quantum Physics

Neutrino Physics

Radiation from the Universe

12 projects

FISH
G-GRANSASSO
HUMOR
LARASE
LIMADOU
LISA-PF
(MAGIA-ADV)
MOONLIGHT-2
PVLAS
(QUPLAS)
SUPREMO
VIRGO

Gravitational waves, Gravity and Quantum Physics

The Dark Universe

Gravitational Waves, Gravity and Quantum Physics : Aerial View

Gravitational Waves

Virgo & LIGO Adv.
LISA-PF

Magia-Adv ??
(atomic fountains 300 m)

G.W., Gravity & Q.M.

General Relativity

Moonlight2 - INRRI (RetroReflectors)
G-GRANSASSO (GiroLaser, Ginger)
LARASE **Lens-Thirring G.R.**

Magia-Adv **atomic fountains 20 m**

Quantum Mechanics

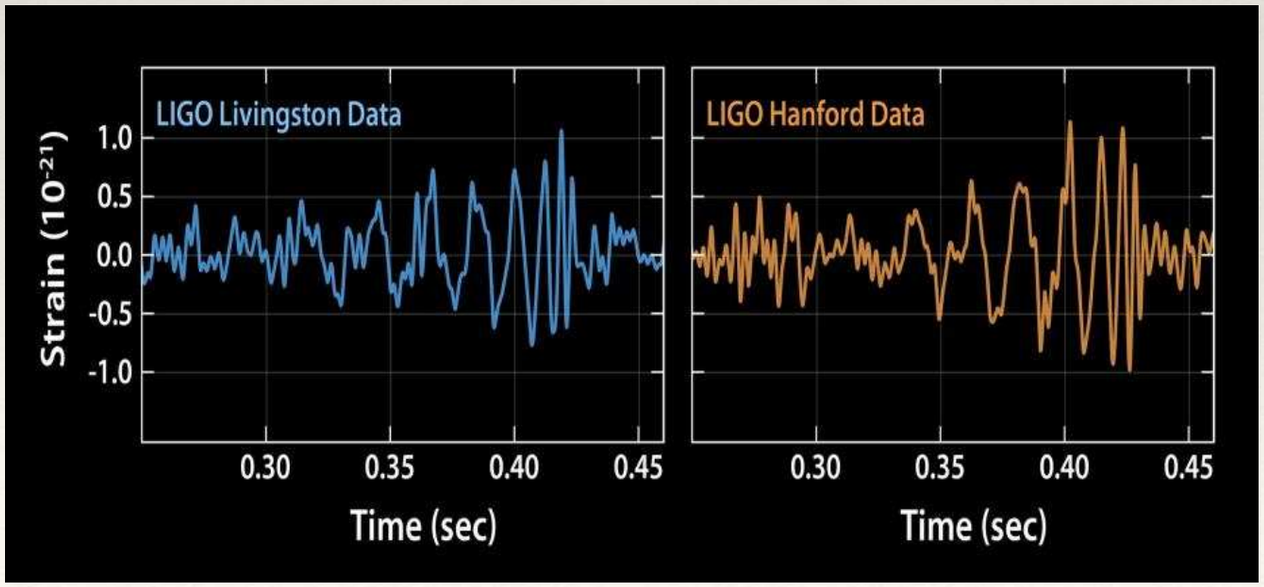
FISH quantum simulations
SUPREMO time variability
HUMOR quantum commutator

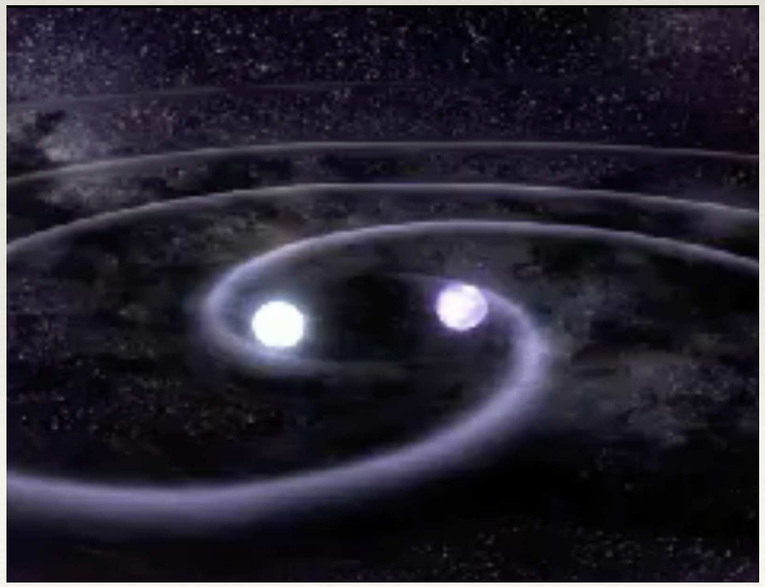
Running
Under construction
Future planning
Closing

Breaking news

Giovanni Prodi
Today

- Two remarkable events recently:
  - A huge one: **discovery of GW from BH merger GW150914**
  - A very significant one: LISA-PF **successful launch and performance**
    - (results to be released on June 6th)
- Top priority short term: have VIRGO part of Run-2
- Top priority medium term: GW astronomy with 3 interferometers

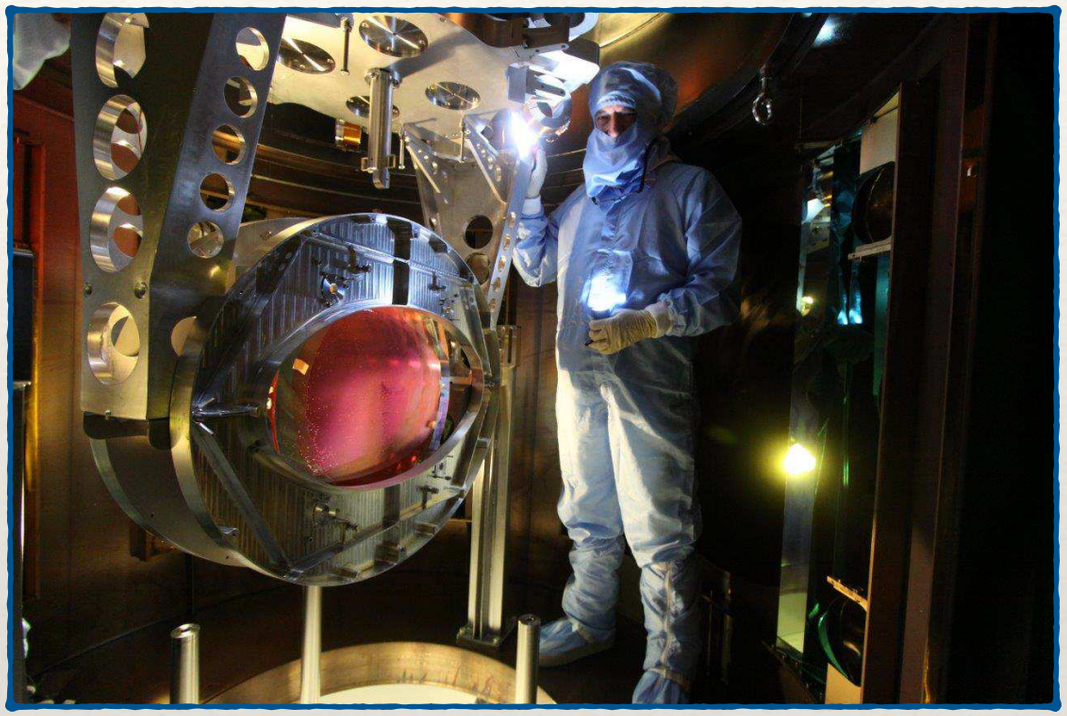




Gravitational waves

Giovanni Prodi
Today

- **Step 1: join Run-2**
  - **Virgo-Ligo Adv. program almost ready to go**
  - Antennas (AURIGA and NAUTILUS) OFF in June 2016



- **Step 2: Birth of GW astrophysics**
  - How many events ? **2 < events < 400 y**

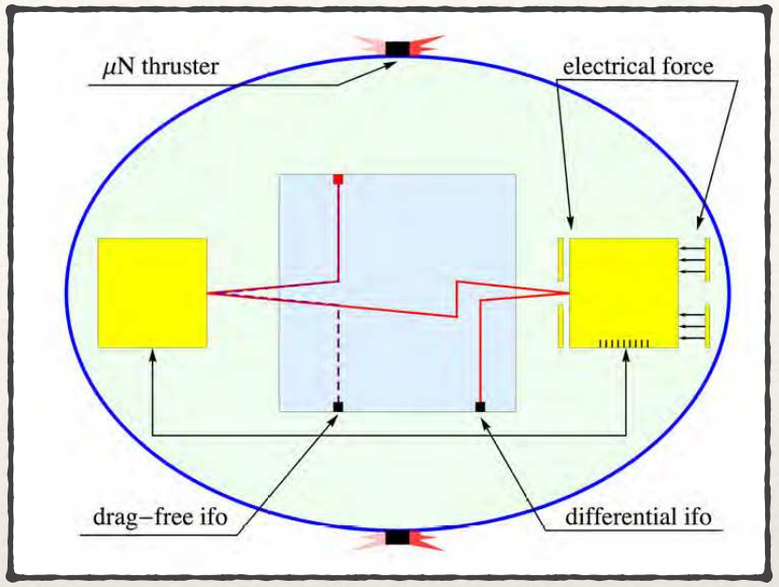
arXiv:1602.03842v1

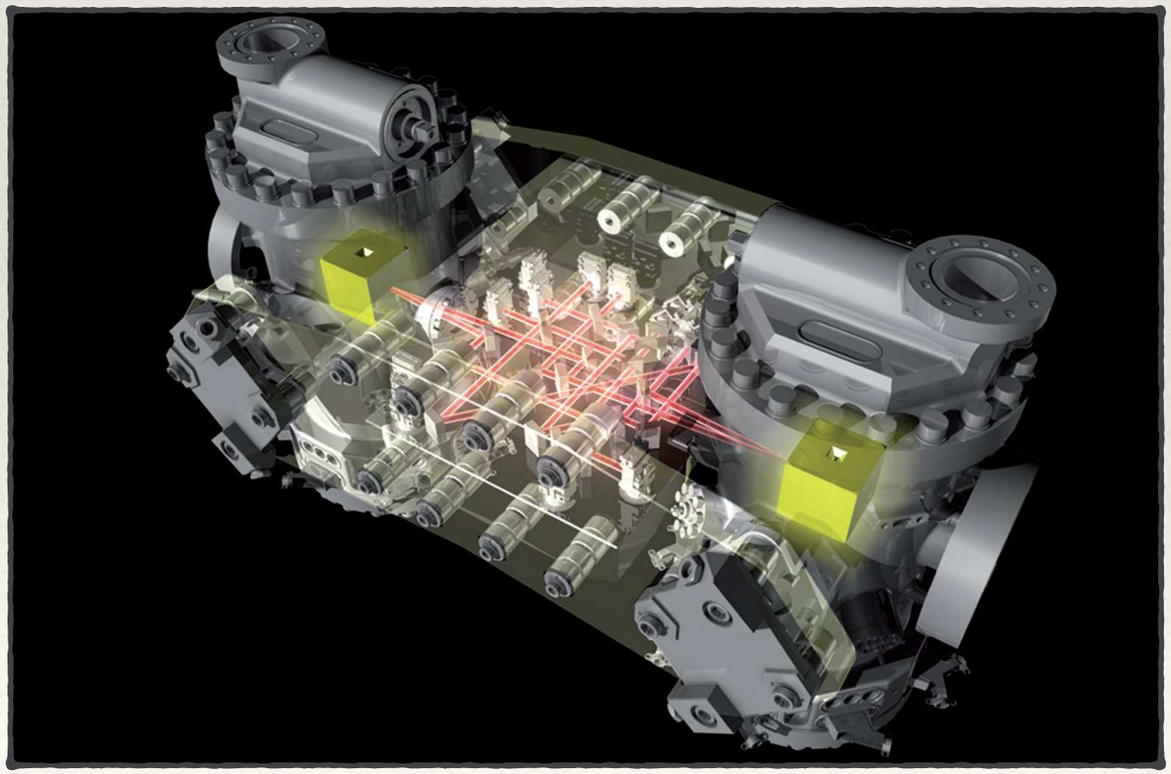
- **Future**
  - LISA-PF launched and running: key step toward low frequency observatory
  - Einstein Telescope for relatively high frequency observatory (long term future)
- **Multi-messenger observation with GW ahead**
- **R&D effort for new technologies** (atom interferometry on ground or space)

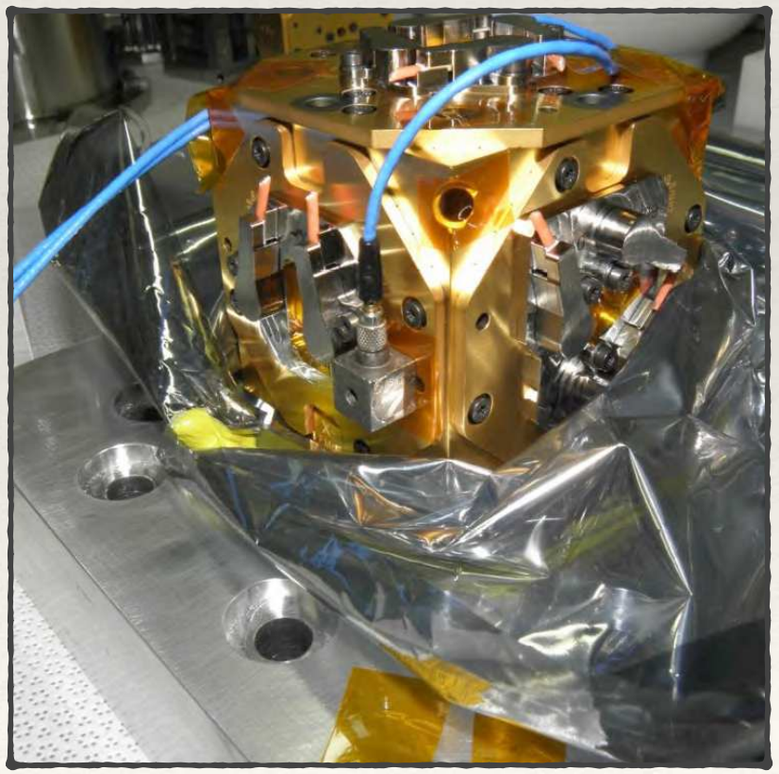
LISA-PF

Massimo Bassan
Today

- 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. 2, 2015 at 5.15 GMT**
  - **Will ESA change plans to make LISA happen earlier than 2034 ? Hopefully. We are ready.**







Final remarks

- **A very rich menu**
  - Maybe, a TOO rich menu…
  - **Available resources** (both money and man-power) **are not enough** to sustain this big bunch of activities
- The INFN CSN2 is working (hard) to prepare a **prioritised plan for each of the four scientific areas**
- Not all things I said we plan will actually happen

Thanks