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
    - **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

- Neutrino Physics
- Radiation from the Universe
- Gravitational waves, Gravity and Quantum Physics
- The Dark Universe
Many diverse places

Underground

Space

Undersea

Deserts

Mountains
**Neutrino Physics**

**ν as a path beyond Standard Model**
- ICARUS-SBL: sterile neutrino search
- SOX: sterile neutrino search

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

**ν as a messenger from the Universe**
- BOREXino: solar, geo neutrinos
- DUNE: CP violation
- JUNO: mixing, hierarchy
- OPERA: mixing
- T2K: mixing, hierarchy, CP
- KM3 (ORCA): hierarchy

**What is the ν mass?**
- HOLMES: direct measurement with μ-bolometers
- EUCLID: indirect measurement with cosmological observations
- CUORE: 
- GERDA:

**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)**

- $P_{\nu_e, \nu_e}$ survival probability
- $E_\nu$ vs. survival probability
- $P_{\nu_e}$ vs. $E_\nu$
- $1 - \frac{1}{2} \sin^2 2\theta$

**After Borexino (2015)**

- Survival probability for all solar neutrino energies
- $P_{\nu_e}$ vs. energy
- $8B$, $7Be$, $pp$, $pep$
• 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 $0\nu\beta\beta$

- Current generation of bolometer experiments are background limited
  - Option: use scintillation light to reduce $\alpha$ 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 (\textsuperscript{82}Se at 95%)
- ZnMoO\textsubscript{4} crystals (\textsuperscript{100}Mo at 99%)

Moscow, Oct.6th, 2015

Marco Pallavicini - Università di Genova & INFN
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
  - $^{144}\text{Ce}$ 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
  - $^{51}\text{Cr}$ 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
The Dark Universe

• Three ways to Dark Matter
  • Direct
  • Indirect
  • Production (LHC)

Production

LHC Experiments (not my job…)

Indirect Direction

AMS-02
Dampe
Fermi
Gamma-400
Pamela

p, pbar, e±
γ, p, pbar, e±
γ, e±
??
p, p, γ, e±

possibly killed by ROSCOSMOS

Direct Detection

CRESST
DAMA-Libra
DarkSide-50 (20t)
Xenon1t (multi-ton)
QUAX

WIMPs
Model Independent
WIMPs
WIMPs, E.M. model dep.
Axions, spin coupling

SM: Standard Model Particle
DM: Dark Matter Candidate

Unknown Interaction
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

- 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
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
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: $0.4 < \text{events} < 400 \text{ y}$
  - 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, $\gamma$, 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
  - \( \sim 8 \text{M€/y} \)
  - 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