

seminarium sprawozdawcze za rok 2018, Świerk, 10/XII/2018

Astrofizyka neutrin i ciemna materia

Piotr Mijakowski



GROUP IN 2018

Part of Warsaw Neutrino group led by prof. Ewa Rondio.
Two main projects:

◉ Super-Kamiokande (2 pers.)

- Piotr Mijakowski (coordinator+research), Katarzyna Frankiewicz (phd student until Sep/2018, now: researcher@NCBJ, next: post-doc at Boston University)
- Topics: *dark matter*

◉ KM3NeT (5 pers.: 1 + 2 post-docs + 1 PhD + 1 MSc)

- Piotr Mijakowski (coordinator, Conference and Outreach Committee, Insitute Board, Review & Resources Board, CORSIKA sim. group coordinator), Piotr Kalaczyński (PhD since Dec/2017), Meghna K.K. (post-doc since May/2018), Rafał Wojaczyński (post-doc since Dec/2018), Jerzy Mańczak (MSc in 2018)
- Topics: *dark matter* (Meghna), *cosmic ray shower simulations & MC in general* (Piotr K.), *neutrino interactions & Glashow Resonance search* (Jerzy)

FINANCING

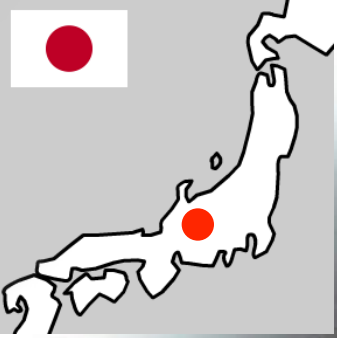
KM3NeT + Super-Kamiokande

1. **NCN: SONATA-BIS**, coordinator: P.Mijakowski, **May/2016-2020**,
1.13 mln PLN

Super-Kamiokande

2. **NCN: Preludium**, coordinator: K. Frankiewicz, **March/2016-/2018**,
100k PLN
3. **EU: Horizon-2020, MSCA-RISE-2014 "SKPLUS"**, **Dec/2014-/2018**,
58.5k EUR for NCBJ, consortium: NCBJ-PW-UAM (Madrid),
coordinator@NCBJ: P.M.
4. **MNiSW: Premia na Horyzont** related to **SKPLUS**, ~50k PLN
5. **MNiSW: projekt współfinansowany**, related to **SKPLUS**, ~30k PLN

SUPER-KAMIOKANDE



Super-Kamiokande

@ Kamioka Observatory (ICRR, University of Tokyo), Japan

located 1km underground

40m

40m



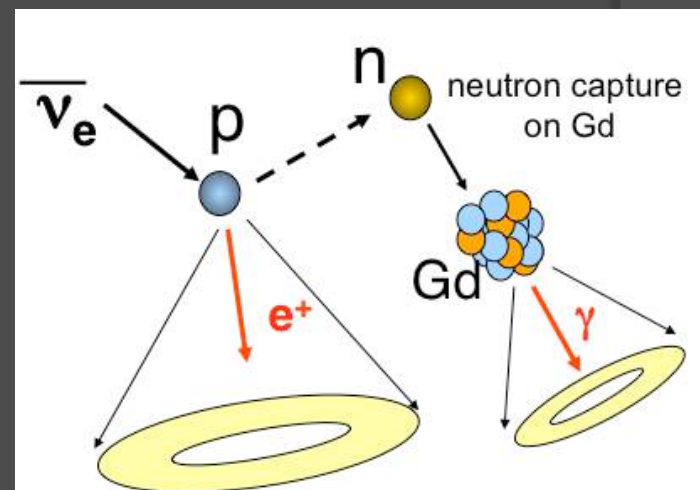
photomultipliers (PMTs) detect Cherenkov light



- 50 kton of pure water (22.5 kton FV)
- inner (ID) & outer/veto (OD) detection regions
- SK runs from 1996
- measures solar, atmospheric, cosmic & accelerator neutrinos
- T.Kajita → Nobel Prize 2015

Super-Kamiokande: TANK WORK

- Physical work at the SK detector upgrade, summer 2018
- 5 people from NCBJ participated, thanks to EU, SKPLUS grant: K.Frankiewicz, P.Kalaczyński, K.Kowalik, P.Mijakowski, G.Żarnecki (3 pers•months in total)
- PMT checks & calibration, rust removal, tyvek installation, surface cleaning → detector will have to be water sealed, before we loose ~1.5 ton of water/day
- GOAL: SK-Gd phase, ~8 tons of gadolinium sulfate dissolved in water (0.2% concentration) increase sensitivity to SN anti- ν which is limited currently by backgrounds
- Possibility to discover diffuse SN background neutrinos by coincidence reaction with n capture (up to ~5 events/year at Super-K & ~800 evts at Hyper-K)
- WORK IS DONE, DETECTOR IS BEING FILLED WITH WATER



TANK WORK



Super-Kamiokande: DARK MATTER

2 independent analyses (PM and KF are performing these works solo)

- Search for DM-induced neutrinos using a fit method

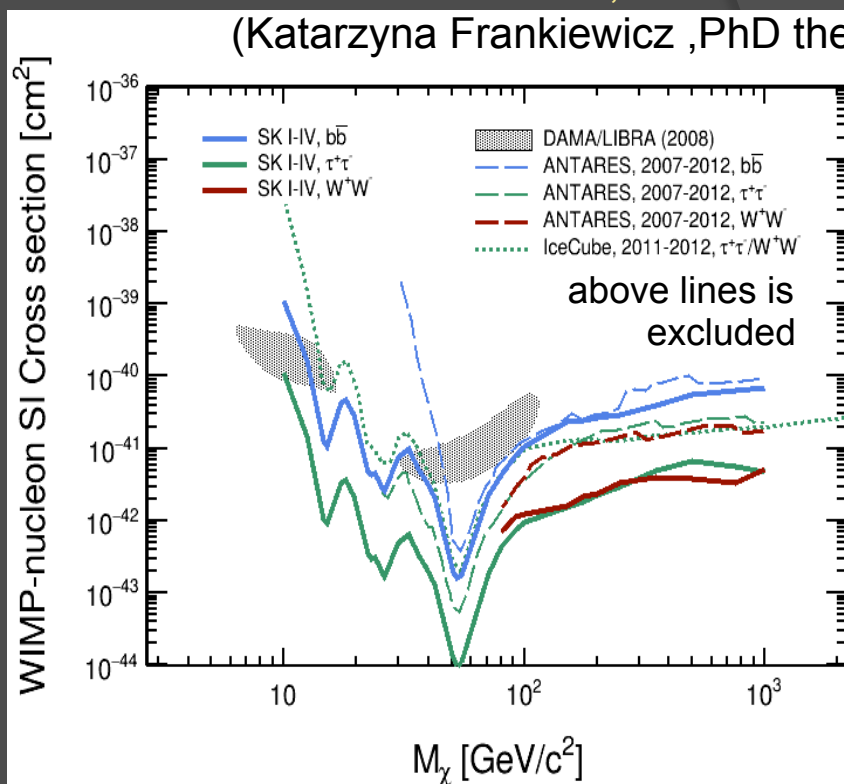
$$\chi\chi \rightarrow \nu\bar{\nu}, W^+W^-, b\bar{b}, \mu^+\mu^- \rightarrow \dots \nu_{e/\mu/\tau}$$

$$\text{DATA} = \underbrace{\text{DM} + \nu \text{ ATM}}_{\text{Monte Carlo}} \quad ?$$

- Galactic Center (by PM): finished in 2017, paper to Physical Rev. D under internal revision in 2018
- Earth WIMPS (by K.Frankiewicz): finished in 2018, paper to PRL under internal revision
 - Result was published in the **PhD thesis** of KF, defended in Sep/2018 → **nominated for distinction by 2 referees**

EARTH WIMP search, SK limits 2018

(Katarzyna Frankiewicz, PhD thesis)

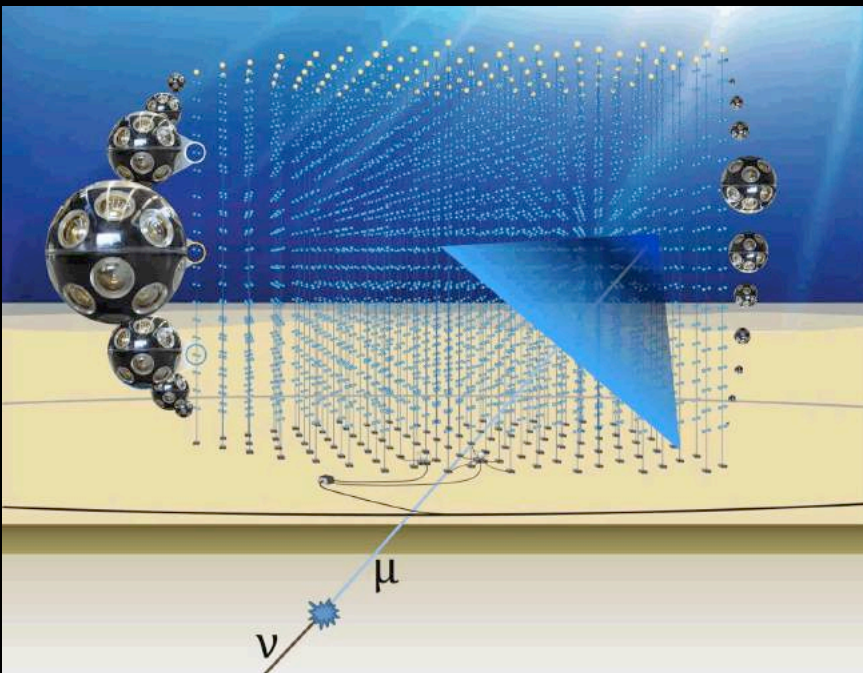


The strongest limits among all neutrino experiments!

- 2018: all SK DM results presented by PM at 3 international conferences (Moriond, TMEX, Dark Ghosts) & 2 seminars

KM3NET

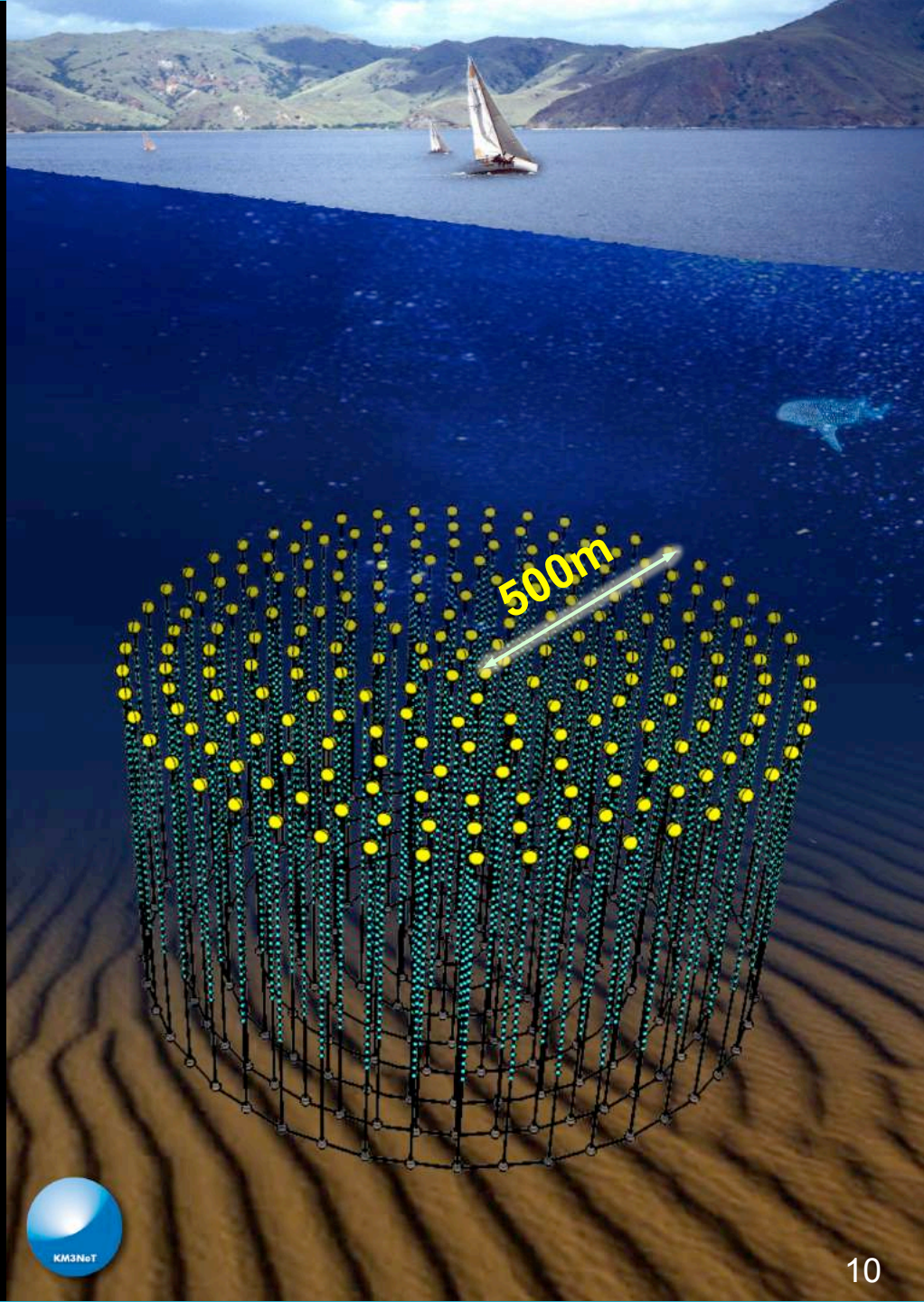
KM3NET



- Modular neutrino research infrastructure in the Mediterranean Sea (aim for $\sim 1\text{km}^3$)

2 DETECTORS:

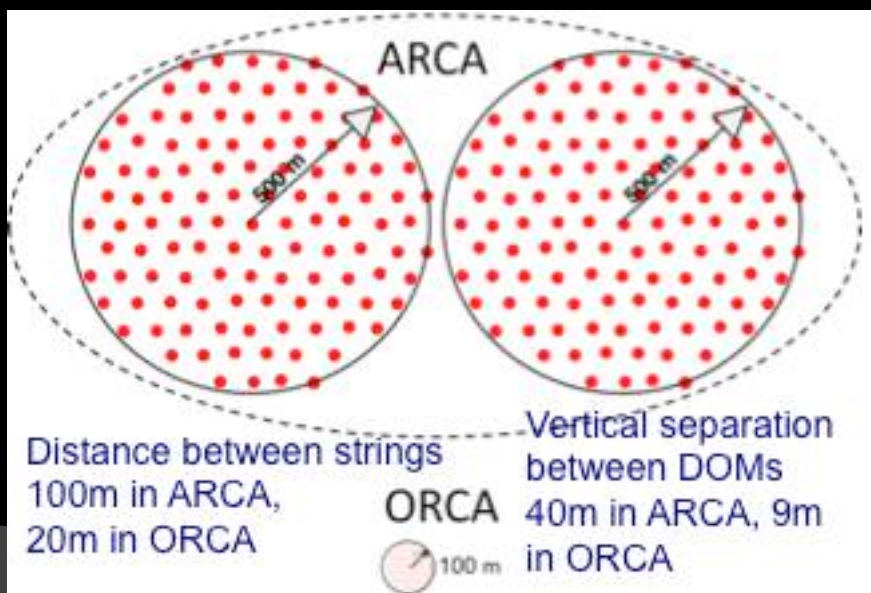
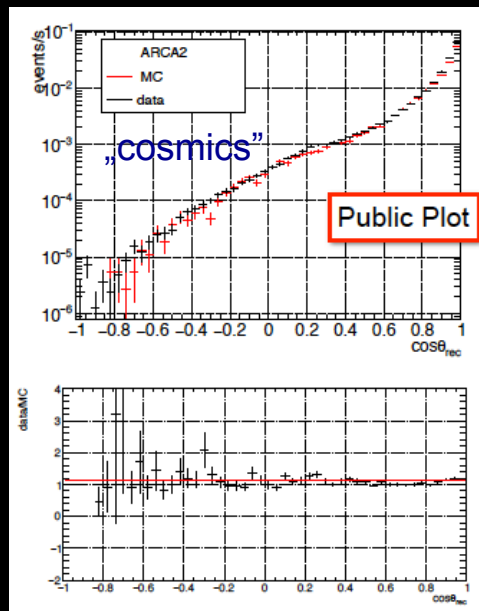
- **ORCA** Toulon (FR) $\sim 2.4\text{km}$ depth
- **ARCA** Capo Pasero (IT) $\sim 1\text{km}^3$, $\sim 3.4\text{km}$ depth



ARCA / ORCA

ARCA (Astroparticle Research with Cosmics in the Abyss)

- GOAL: 2x115 strings, ~1km³
- Phase I: 24 strings, 0.1 km³
- So far: 3 strings



ORCA (Oscillation Research with Cosmics in the Abyss)

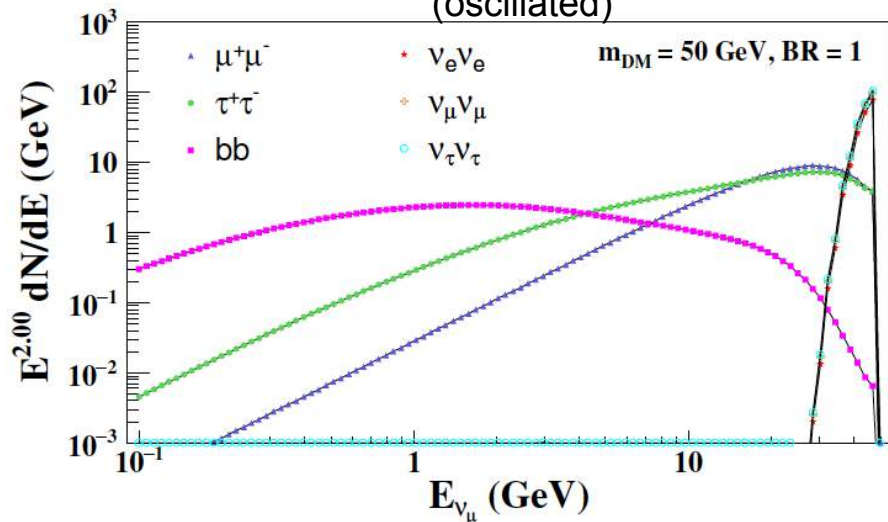
- study of atmospheric ν
- 1st stage: 6 strings in KM3NeT-FR (Toulon) already funded, 3 already deployed
- next phase: 115 strings, 3.7Mton (x20 bigger than Hyper-K)

KM3NET: our activities in 2018

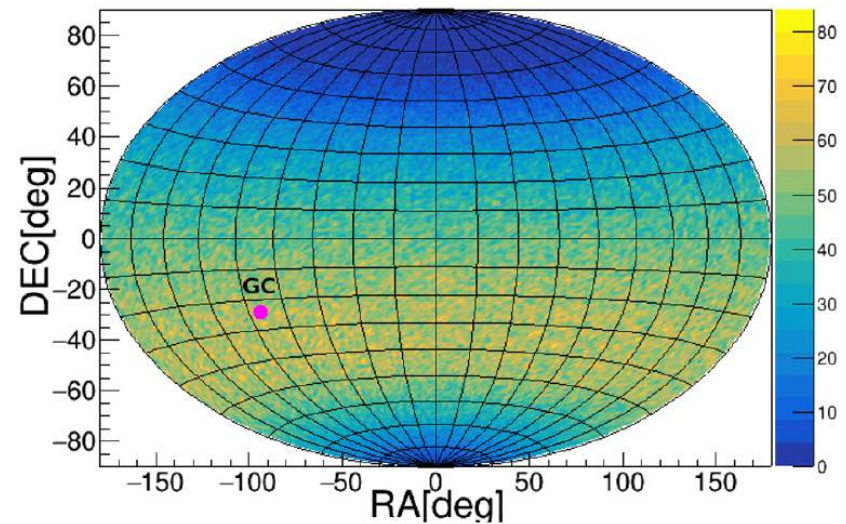
1. Dark Matter: sensitivity search for DM-induced ν s from Galactic Center and halo using ORCA detector, *Meghna K. K.*

- in 1 year ORCA is expected to reach 3-10x better sensitivity than Super-K in 20 yrs
- post-doc started in May/2018, work in progress ...

example: simulated signal spectra from GC
(oscillated)



atm. ν s bkg seen in ORCA in RA/DEC (MC)



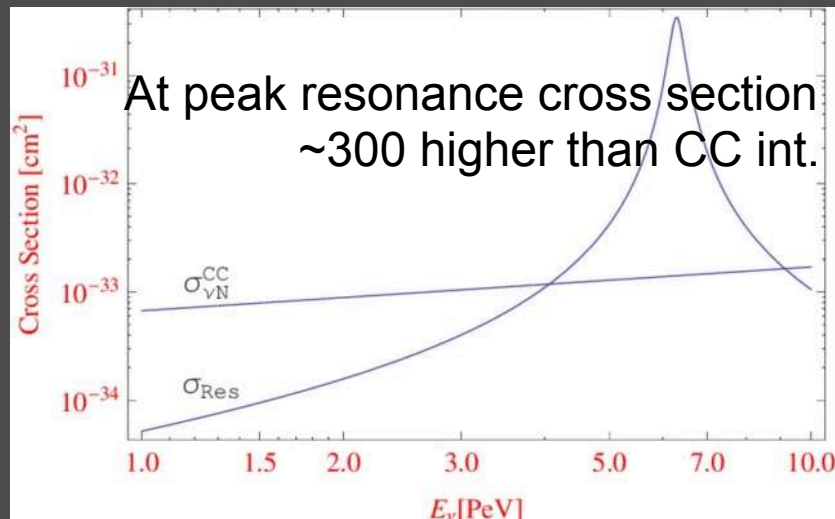
KM3NET: our activities in 2018

2. MSc thesis:

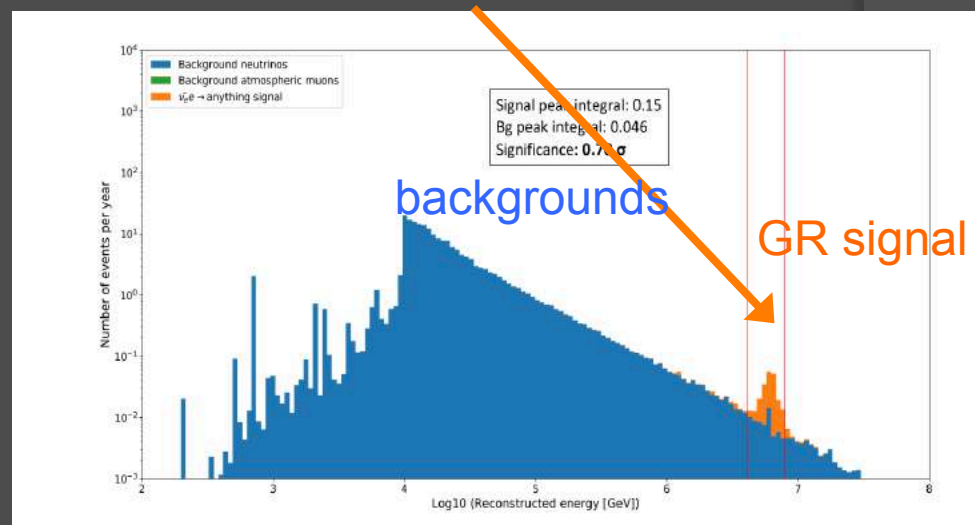
“Sensitivity study for the Glashow Resonance detection at KM3NeT”, *Jerzy Mańczak*

- thesis graded with 5 (supervised by PM and M.Posiadała-Zezula UW),
- Jerzy currently PhD @ fellow KM3NeT group in Valencia

electron anti-n interactions@6.3 PeV



expected signal after reconstruction



reconstructed ν energy

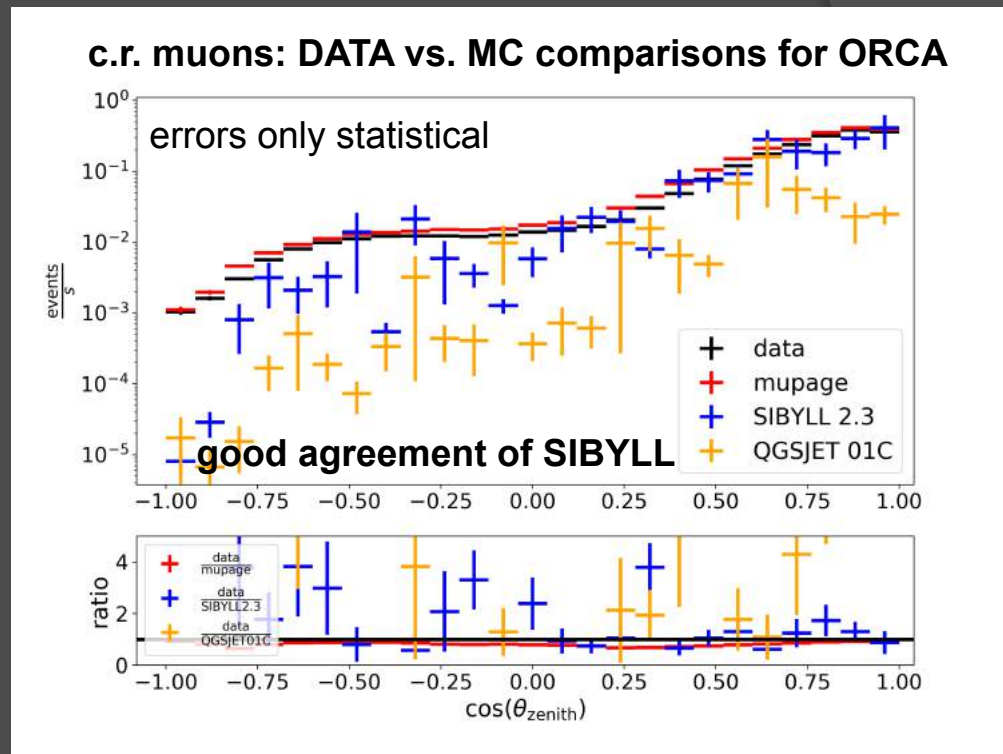
Full ARCA detector: 0.7σ in 1 year, 3σ in 9.2 yrs

KM3NET: our activities in 2018

3. ARCA/ORCA Monte Carlo work: CORSIKA based cosmic ray shower simulations, *Piotr Kalaczyński (PhD student)*

- atm. ν and muons are main bkg in search for astrophysical neutrinos
- full detector simulation chain: CORSIKA products @ sea level, propagation in water, interactions in detectors, light prod. simulation, trigger, detector reconstruction etc.
- GOALS: compare with cosmic ray muon data from phase-1 ARCA & ORCA detectors**, self-veto study, search for charm component of the cosmic rays
- CIŚ is being used for some of these simulations*

Reaching agreement of MC with DATA
→ important milestone for the ARCA/ORCA prototypes due to Piotr's work



So far, no one has measured cosmic rays at the depth of 3.4 km of water

**OUTREACH:
COSMIC WATCH**

Cosmic Watch

a particle detector you can build yourself

- Self-contained, pocket size detector
- Based on plastic scintillator and silicon PMT
- USB powered, open-source software available
- Easy to build and inexpensive (~100 USD)
- Broad educational applications



Web page: www.cosmicwatch.lns.mit.edu



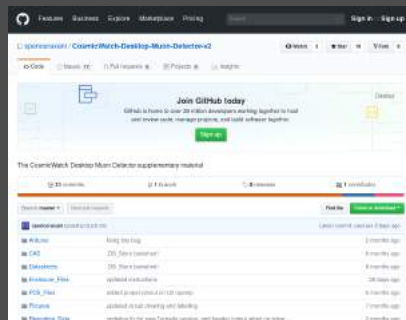
Facebook:

www.facebook.com/cosmicwatch.mit

GitHub repository:

→ all necessary information

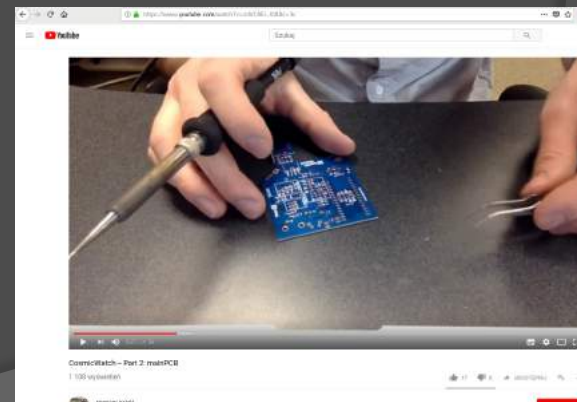
[github.com/spenceraxani/
CosmicWatch-Desktop-Muon-Detector-v2](https://github.com/spenceraxani/CosmicWatch-Desktop-Muon-Detector-v2)



Recent Paper:

S. N. Axani, K. Frankiewicz, J. M. Conrad,
*“The CosmicWatch Desktop Muon Detector:
a self-contained, pocket sized particle detector”*
JINST 13 (2018) no.03, P03019

YouTube: step-by-step instructions



www.youtube.com/watch?v=e4IXzNiNxgU&

● NCBJ, Education and Training Division

Program: “**Detectors for schools**”
→ Schools can borrow particle detectors to perform various measurements and discuss the results. We provide some ideas, instructions and software.
<https://www.ncbj.gov.pl/edukacja/detektory-szkol>

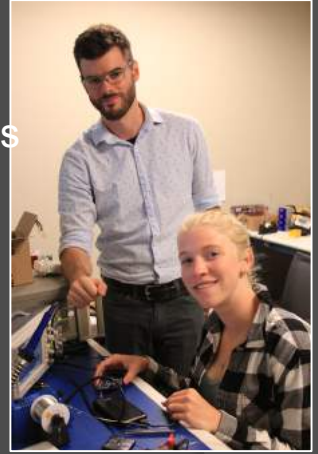
Workshop for teachers, Olsztyn



30 Detectors

● Wisconsin IceCube Particle Astrophysics Center

50 Detectors
Madison, USA
Program for high school and undergraduate students



Learn a new advanced laboratory experiment well enough to teach it with confidence! 3 day intensive program

● Adler Planetarium Chicago, USA

Program “**Far Horizons**”: Design an experiment and launch it into space!



● CREDO project



Cosmic-Ray Extremely Distributed Observatory
Konrad Kopański, Wojciech Noga

Near Space Conference Turuń, 22/09/2018



Katarzyna Frankiewicz
Bartosz Maksiak
Armand Budzianowski
Andrzej Bigos
Spencer Axani (MIT)

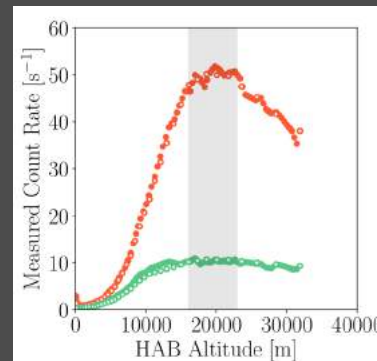


Two CosmicWatch detectors
sent for high attitude balloon
flight ~ 32 km

Detector presentation



Interesting data:
count rate vs altitude



Regener-Pfotzer maximum
visible ~ 19 km

Article in Świat Nauki 11/18



Edukacyjny balon

Pod koniec września, podczas odbywającej się w Turku międzynarodowej konferencji Near Space 2018, balon meteorologiczny wymiścił w bliską przestrzeń kosmiczną przygotowaną przez naukowców z Narodowego Centrum Badań i Zastosowań kapsułę zawierającą specjalnie przystosowany zestaw dwóch detektorów edukacyjnych CosmicWatch

„Naszym celem było dotarcie pomiarów pokazujących, jak zmienia się nasycenie promieniowania kosmicznego w takiej wysokości” - wyjątkowo dr Armand Budzianowski (ONR), który był opiekunem projektu

było możliwe w ramach tego wędrownego balonem bezzałogowym. Balon wzniósł się do statystycznej na wysokości około 32 km. Tam, zgodnie z przewidywaniami, reaktor ciałek na zewnętrznej powierzchni balonu spowodowała powłoka jego powłoki. Od tego momentu kapsuła z przystosowanymi zwoleńcami opadła na powierzchnię Ziemi. Kapsuła kapsuła była stale monitorowana dzięki danym telemetrycznym przekazywanym drogą radiową, natomiast dane zbierane podczas lotu przez detektory były zapisywane w pamięci, które uaktywniły dopiero na ziemi”

Projekt ma przede wszystkim znaczenie edukacyjne. Wyniesiony w górę warstwy atmosfery zestaw dokonywał pomiarów różnicą promieniowania kosmicznego, które nie uaktywniły



OTHER ACTIVITIES

TMEX 2018 CONFERENCE

- As a whole neutrino group@NCBJ we organized **TMEX 2018 WCP** conference, **Sep/2018** in Warsaw
- **SKPLUS** grant context
- 3 days, ~50 participants, 35 invited talks
- Distinguished guests: director of J-PARC lab (Japan): T.Kobayashi; director of Canfranc lab. (Spain): C. Peña-Garay; T2K spokesman: T.Nakaya ...



3rd Symposium Theory Meeting Experiment

TMEX 2018 WCP

European Workshop on
**Water Cherenkov Precision Detectors
for Neutrino and Nucleon Decay Physics**

19 – 21 September 2018, Warsaw, Poland
Centre for Innovation and Technology Transfer Management
Warsaw University of Technology

Super-Kamiokande
Hyper-Kamiokande

Topics:

- Water Cherenkov experimentation
- Electronics/DAQ
- Simulation & reconstruction
- Next generation experiments
- Neutrino interactions
- Neutrino oscillations
- Astrophysical connections

International Advisory Committee:
S. Bolognesi (CEA/DAPNIA Saclay),
M. C. González-García (UB/SUNY), A. Heijboer (NIKHEF),
J. Kiryluk (SUNY), Y. Nishimura (ICRR/NNSO UTokyo),
H. Sekiya (ICRR/NNSO UTokyo), D. Wark (Oxford/STFC),
R. Wendell (Kyoto Univ.), A. Zalewska (IFJ)

Organizing Committee:
K. Kowalik (NCBJ), L. Labarga/chair (UAM),
J. Lagoda (NCBJ), P. Mijakowski (NCBJ),
M. Posiadata-Zezula (UW), E. Randio/chair (NCBJ),
J. Zalipska (NCBJ), M. Ziembicki (PW)

<http://neutrino.ncbj.gov.pl/tmex2018wcp>

Logos include: NATIONAL CENTRE FOR NUCLEAR RESEARCH (NCBJ), UA (University of Applied Sciences), Warsaw University of Technology, UNIVERSITY OF WARSAW, Faculty of Electronics and Information Technology (IFIT), CZliTT, European Commission, Horizon 2020 European Union Funding for Research & Innovation, NATIONAL SCIENCE CENTRE (NCN), and Secretariat contact: tmex2018wcp@ncbj.edu.pl, milvia.soubounou@uam.es

LOI WITH KOŹMIŃSKI UNIVERSITY

- Letter of Intent between NCBJ and Koźmiński University, Oct/2018
- Intended collaboration in the field of applied machine learning (ML) and artificial intelligence (AI)
 - Cross science-industry grant applications
 - Working group formed between NCBJ, Koźmiński Univ. and DZP law company (one of the largest in PL) → ML/AI in legal industry, aim for NCBiR, *PM* coordinator from NCBJ
 - Koźmiński Univ. started new MSc. course “Big Data Analysis” → NCBJ has expertise, possible educational support



SUMMARY FOR 2018



○ Super-Kamiokande

- Detector upgrade work
- DM analysis: Earth WIMP search & ON-/OFF-source Galactic WIMP search in PhD thesis of **Katarzyna Frankiewicz**: defended in Sep/2018, distinction
- 2 collaboration papers in preparation (one by P.Mijakowski, one by K. Frankiewicz)

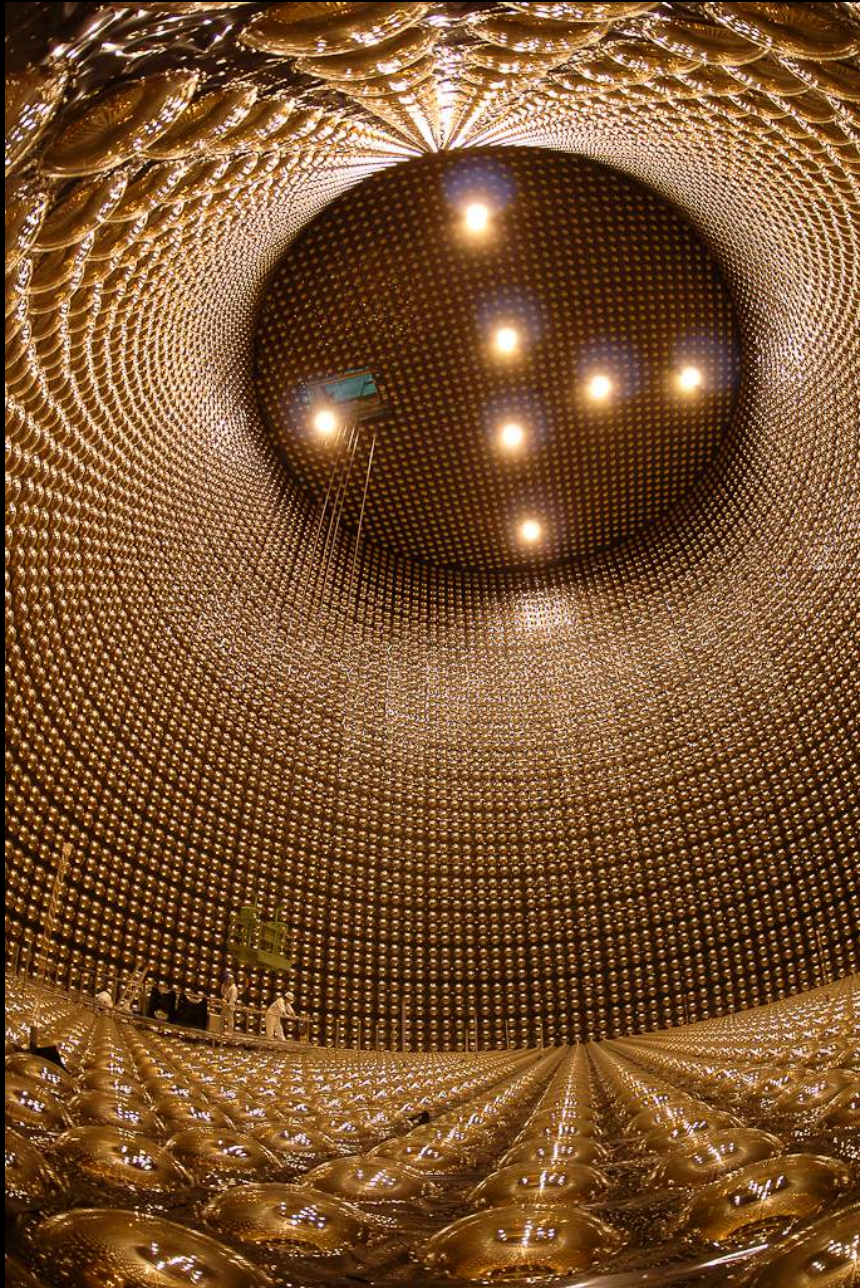
○ KM3NeT

- MSc. thesis by **J. Mańczak** (Glashow Resonance & neutrino interactions) → defended in Sep/2018
- Progress in Monte Carlo simulations of cosmic rays → getting agreement with ORCA and ARCA data, **Piotr Kalaczyński**

○ TMEX conference

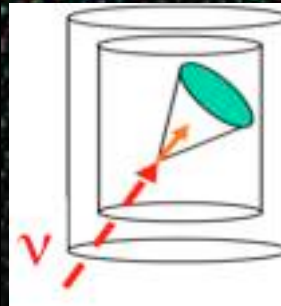
○ Cosmic Watch in progress by **K. Frankiewicz**

BACKUP



**Detected Cherenkov light
allows for reconstruction of:**

- lepton momentum (neutrino energy)
- lepton direction
- lepton flavor (e-like vs. μ -like, good separation possible)



Future: Hyper-Kamiokande

- start 2026 (after 7 years construction)
- main goal: neutrino mass hierarchy and δCP
- some astro potential: SN, DSNB (~ 2 evts per day), WIMPs, cosmic neutrinos

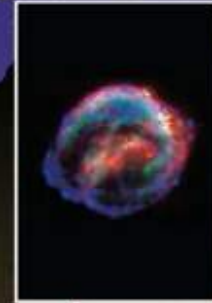
Accelerator Neutrino beam from J-PARC



Atmosphere



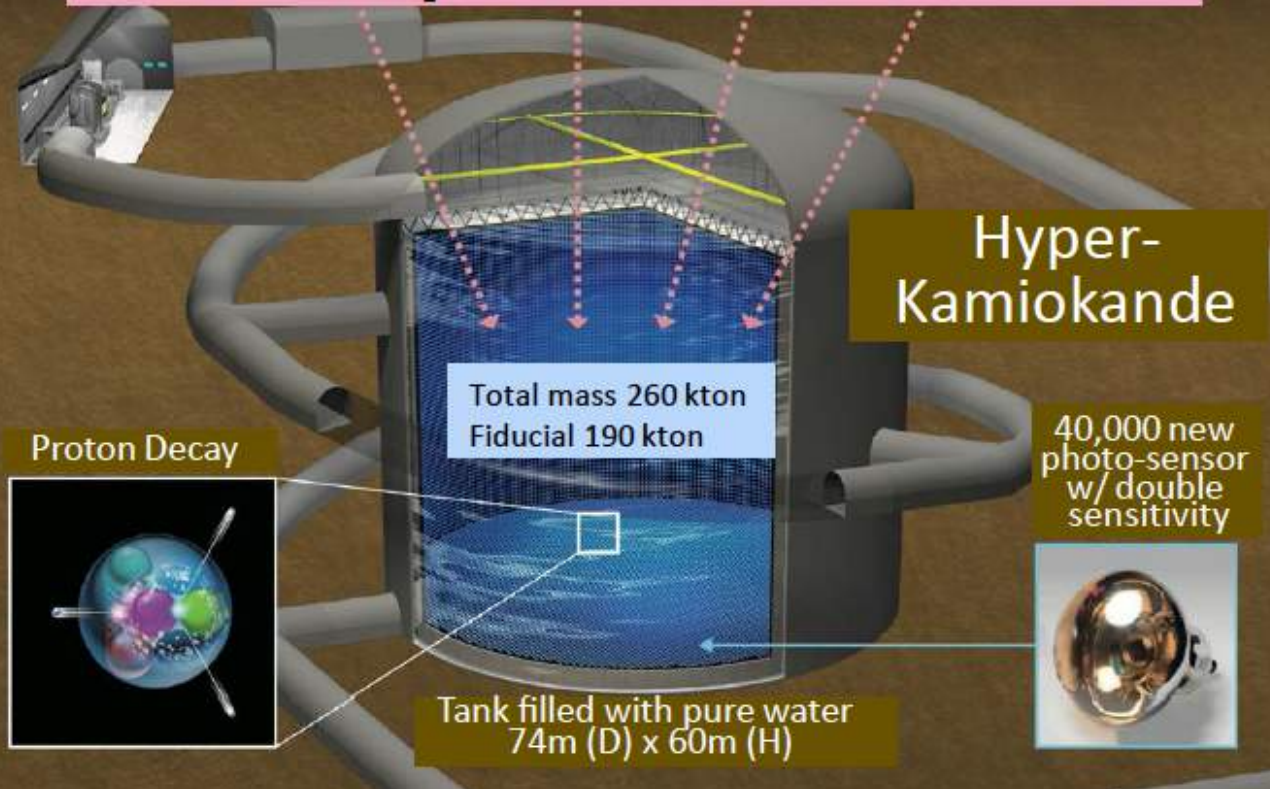
Supernova



Sun



~ 10 x Super-K fiducial mass



Proton Decay



Total mass 260 kton
Fiducial 190 kton

Tank filled with pure water
74m (D) x 60m (H)

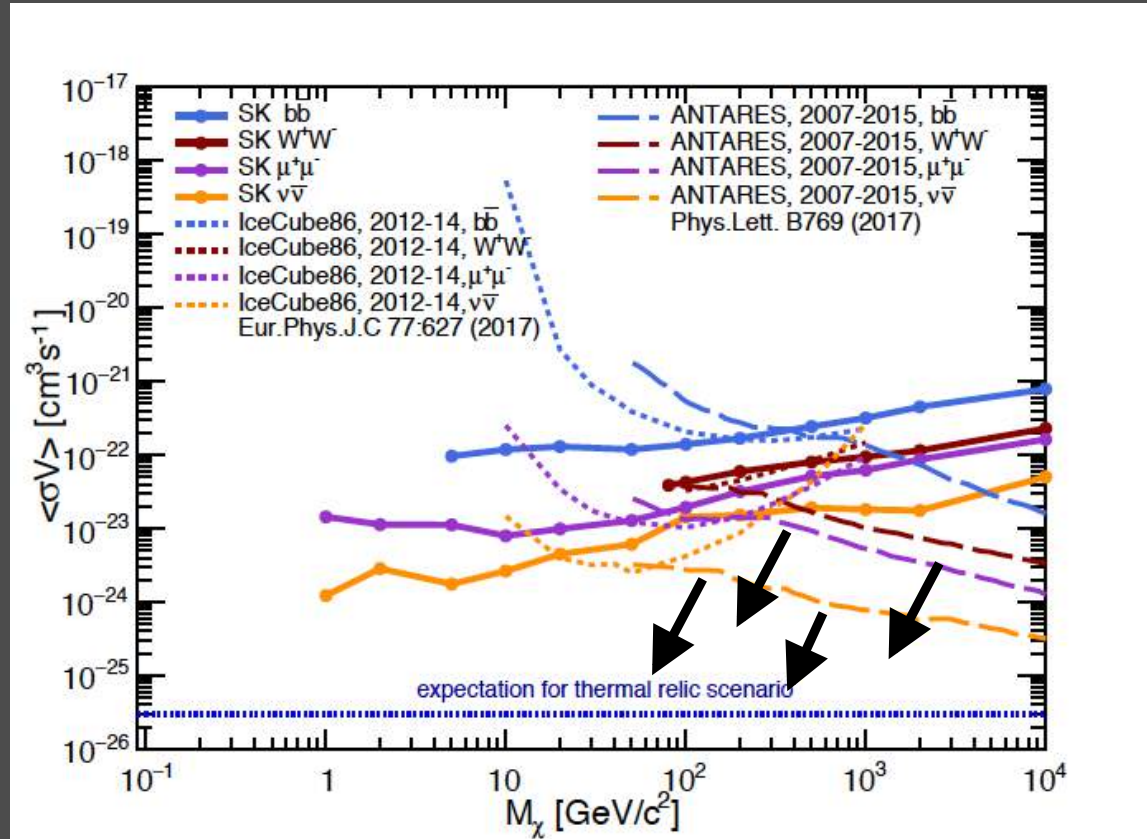
Hyper-Kamiokande

40,000 new photo-sensor
w/ double sensitivity



DM: Prospects at KM3NeT

Strong limits from Antares (0.01km³, 12 strings) → great potential of KM3NeT (0.1 → ~1km³, 230 strings)



Super-K: 0.45 Mton•yrs (current limit)
 Hyper-K: 3-10x improvement in 20 yrs
 ORCA: 3-10x imprv. in ~ 1 yr (wrt. SK)
 ARCA-2 blocks: 30-10²x imprv. in ~ 1yr