

VLVnT15 - Rome 14-16 September 2015

# KM3NeT-ARCA project status and plans

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# KM3NeT



### KM3NeT is a multi-site infrastructure in the Mediterranean sea hosting neutrino detectors.

#### The main elements of the design are:

Vertical Detection Units (DUs) hosting Multi-PMT (DOMs) with power and data distributed by a single backbone with breakout at DOMs and optical data transmission

Seefloor Network

Building blocks with 115 DUs

A Multisite detector with different physics goals, same technology but different sensor densities:

KM3NeT-ORCA (*Oscillation Research with Cosmics in the Abyss*) for the measurement of the neutrino mass hierarchy at the French site

KM3NeT-ARCA (Astronomy Research with Cosmics in the<br/>Abyss) for the high energy neutrino astronomy at the<br/>Italian site2



KM3NeT-ORCA talk by D. Samtleben

# Outline

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- ★ Main element description
  - ★ Digital Optical Module
  - ★ Detection Unit
- ★ Prototype results
  - ★ Detection Unit prototype validation
- ★ Status
- ★ Expected performance of KM3NeT-ARCA
  - ★ diffuse fluxes
  - ★ point-like sources

# Digital Optical Module

### A new design for optical sensors developed by the collaboration

A 17-inch pressure-resistant glass sphere with 31 3-inch PMTs

19 PMTs looking down 12 PMTs looking up





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#### photocathode aerea $\approx$ 3 × 10-inch PMTs

DOM talk by D. Vivolo - Parallel session A

# Digital Optical Module

Time

Threshold

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- ★ Reflective ring → 20–40% gain in effective photocathode area
- ★ Single penetrator
- ★ Low power consumption → <10 W per DOM
- ★ FPGA readout for each individual PMT
  - ★ sub-ns time stamping
  - $\star$  time over threshold (ToT)
- ★ Calibration
  - ★ LED & acoustic piezo

DOM electronics talk by D. Real and D. Calvo- Parallel session E PMT characterization talks by V. Giordano - Parallel Session A Test bench talks by B. Baret and C. Mollo- Parallel Session F

Amplitude



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# Detection Unit

- ★ String-type with 18 optical modules
- ★ Mechanical structure made of two Dyneema® ropes, anchor and buoys to keep taut the string
- ★ Backbone (VEOC): oil filled tube (~6mm diameter) with 2 copper conductors and 18 fibres; break out of cable at each DOM
- ★ Base module with opto-electronics (DWDM) for data transmission
- ★ Interlink cables for connection to the sea floor network.



# DU deployment



Launcher vehicle ~ 2m diameter





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★ Rapid deployment

★ Autonomous unfurling

★ Recoverable

# Prototypes

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- ★ April 2013 June 2014 string mechanical tests
  - ★ Several deployments → Successful demonstration of deployment concept and of the functionality of the VEOC cable
- ★ April 2013 / November 2014 DOM prototype validation
  - ★ One DOM deployed at 2500m at the French site on the Instrumentation Line of ANTARES → Successfully demonstrated the functionality and performance of DOM (results published in Eur. Phys. J. C (2014) 74:3056)
- ★ May 2014 / July 2015 Detection Unit prototype validation
  - ★ A 3 DOM DU deployed at 3500m at the Italian site → Successfully demonstrated the functionality of DU and calibration methods (paper to be submitted to Eur. Phys. J. C)

# DU prototype

### **DU Prototype with 3 DOMs: proof of DU functionality**

- ★ 2 DOMs with ETEL D783FLA PMTs
  1 DOM with Hamamatsu R12199-02
  PMTs
- ★ Test of the read-out, DAQ, connection
- ★ Fast and reliable methods for time calibration developed:
  - ★ calibration of PMTs inside the DOM (Intra-DOM calibration) with 40K
  - ★ calibration between DOMs (Inter-DOM calibration) with LED nano beacons and atmospheric muons



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# DU prototype results



Photon counting

N<sub>coinc</sub>>7 strongly reduces <sup>40</sup>K contribution

#### Rate of PMTs in the DOM

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#### Directional sensitivity

Upper PMTs see more events ⇒ directional information from single storey

Very good agreement with Monte Carlo predictions (no normalization factors in the spectra)

## In situ detector time calibration



# Moon shadow

- ★ Angular resolution and absolute pointing with the moon shadow
  - **\star** detection at 5 $\sigma$  in 1 month
  - ★ angular resolution for downgoing muons of 0.4°
  - pointing accuracy of 0.1° at
    3σ level

talk by M. Sanguineti- Parallel session F

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#### Monte Carlo simulation

#### **KM3NeT** preliminary



# Not covered in this talk...

- **★** Time calibration talks by V. Kulikovskiy and Gerard Kieft Parallel Session F
- **★** PMT position measurement talks by F. Simeone and R. Lahmann Parallel Session C
- **★** Data transmission talk by S. Pulvirenti Parallel Session E
- **Trigger and Data Acquisition** *talk by C. Pellegrino Parallel Session E*
- ★ Data Base talk by S. Bozza Parallel Session E
- ★ Live Monitoring and Quasi-Online Event Reconstruction talk by T. Gal Parallel Session E
- **★** Grid-Computing talk by C. Filippidis- Parallel Session G

.... and sorry if I forgot someone





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a lot of work

# KM3NeT timeline

### ★ KM3NeT Phase-1:

- ★ Construction: 2014 2016
- ★ Funded with 31 million Euro
- ★ 31 detection units will be deployed in 2015-2016
- ★ Sites: KM3NeT-It (24 DUs), KM3NeT-Fr (7 DUs)

### Construction started

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### ★ KM3NeT 2.0: Two-site infrastructure

- ★ ARCA detector for high energy neutrino astronomy at the KM3NeT-It site
- ★ ORCA detector for NMH studies with atmospheric neutrinos at the KM3NeT-Fr
- ★ Construction: 4 years (2017 2020)
- ★ Additional cost: 90 M€ (not yet funded)
- ★ Proposed to ESFRI Letter of Intent in preparation

# KM3NeT: the status

- ★ Detection Unit (DU-1) in the full configuration (18 DOM) ready for deployment at the french site
- ★ DU-2 to be deployed at the italian site now in the integration phase
- ★ DOM mass production started 3 integration sites already equipped
- ★ DU integration started 2 integration sites in operation

DU 2 deployment in autumn DU1 deployment to be scheduled

#### DOMs in the dark room

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Integration of the base container





## KM3NeT-phase 1@ italian site

talk by R. Papaleo - Parallel session I



8 towers with the NEMO design talks by A. Biagioni, C. Nicolau, D. Favaro - Parallel session E E. Leonora - Parallel session I G. De Bonis - Parallel Session F

### ready for the installation of DUs

CTF: Cable Termination (Frame) : Secondary Junction boxes : Tower DU : String DU PPM-DU Dunction box Tunction box

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#### Shore station



#### Cable termination frame Feeds & connects 4 JBs



## KM3NeT-ARCA

Two building blocks of 115 DUs (about  $1 \text{ km}^3$ ) to be installed at the Italian site at 3500m

- ★ 18 DOM per DU
- ★ Vertical DOM spacing 36 m
- ★ Inter-DU spacing 90 m ≈10km





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#### KM3NeT-ARCA Phase1 (32 DUs)

- ★ 10 times the ANTARES volume
- ★ expected sensitivity 3-4 better than ANTARES

# KM3NeT-ARCA physics case

### \* Main objectives:

- Detection of the IceCube diffuse flux from a different field of view and better angular resolution
- Detection of point-like sources





# The IceCube flux

#### Uncertainties on the spectral function



## Diffuse fluxes

#### Performance of KM3NeT-ARCA to the cosmic IceCube flux

★ Benchmark: IceCube flux (isotropic and flavour symmetric)

one flavour flux

$$\Phi(E) = 1.2 \cdot 10^{-8} (E/1 \text{ GeV})^{-2} \exp(-E/3 \text{ PeV}) \text{ GeV}^{-1} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$$

M. G. Artsen et al., Science 342 (2013)

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tested also φ(E)=2.06 10<sup>-18</sup> (E/100TeV)<sup>-2.46</sup> GeV<sup>-1</sup> cm<sup>-2</sup> s<sup>-1</sup> sr<sup>-1</sup> and similar results found *M. G. Artsen et al., Phys.Rev.D* 91 022001 (2015)

★ All flavours analysis: cascade and track events





1083 TeV CC  $\, \nu_{\, \rm e} \,$  event

# Signal and background generation

Monte Carlo generation:

★ source: all flavours  $\nu_{\mu}$ - $\nu_{e}$ - $\nu_{\tau}$  simulated (NC+CC)

★Background:

- ★ atmospheric neutrinos:
  - Honda model (M. Honda et al., Phys. Rev. D 75 (2007) 043006) with knee correction
     (M. G. Aartsen et al., Phys. Rev. D 89 (2014) 062007)
     for the conventional component
  - Enberg model (R. Enberg et al., Phys. Rev. D 78 (2008) 043005) with knee correction for the prompt component
- ★ large atmospheric muons sample (about 3 years of live time)

Source and atmospheric neutrino background spectra



# Systematic uncertainties

#### **Detector and medium uncertainties**

- ★ Water optical properties
  - ★ Scattering length (±10%)
  - ★ Absorption length ( $\pm 10\%$ )
- **\star** PMT effective area (±10%)
- ★ Random azimuthal rotation of the DOM  $(3^{\circ}/6^{\circ}/9^{\circ})$

#### **Atmospheric neutrino flux uncertainties**

- ★ Prompt component (Enberg model high/low prescription)
- ★ Conventional component (Honda flux ±25% in the normalization factor)



water is a clean and homogeneous medium

# Diffuse flux cascade channel

★ Full sky analysis

talk by L. Fusco - Parallel session D

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- ★ All the events reconstructed with several reconstruction strategies
- ★ A preselection applied to reject most of the atmospheric background
  - ★ Trigger, containment cut and cut on the Time over Threshold (Energy cut)
- ★ Final cut on the preselected events based on Multivariate analysis (Boost Decision Tree)
- ★ Evaluation of the flux at different significance with the Max. likelihood method



# Diffuse flux cascade channel

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angular resolution less than 2 degrees energy resolution less of 10 %

# Diffuse flux track channel

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- ★ Up-going track analysis
- ★ A preselection applied to reject most of the atmospheric background
  - cuts on reconstructed zenith angle, reconstruction quality parameter and on the number of hits (Energy cut)
- ★ Evaluation of the flux at different significance with the Max. likelihood method

angular resolution of the selected events of 0.18 degrees energy resolution of the selected events 26 % in the log(E<sub>µ</sub>)

## The diffuse flux

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discovery at  $5\sigma$  in less than 1 year (combined analysis) major sources of systematic uncertainties taken into account

## Diffuse flux from the Galactic Plane



## Galactic sources

talk by U. Katz on behalf of A. Trovato - Parallel session D

### Benchmark: the SNR RXJ1713 and the PWN Vela X

gamma observation



★ Neutrino spectra predicted using measured gamma spectra with the 100% hadronic emission and transparent source hypotheses

¶ S.R. Kelner, et al., PRD 74 (2006) 034018 and § F.L. Villante and F. Vissani, PRD 78 (2008) 103007

★ spectra cutoffs of the order of few tens of TeV

★ extension 0.6° (RXJ1731) and 0.8° (Vela X)





## Resolution for track-like events



angular resolution of the selected events of 0.2 degrees ( $E_{\nu}$ >10 TeV) energy resolution of the selected events 27 % in log( $E_{\mu}$ ) for 10 TeV <  $E\mu$  < 100 PeV

# Galactic sources

- ★ Up-going muon neutrino analysis
- ★ A preselection cuts applied to reject most of the atmospheric background
  - ★ cuts on reconstructed zenith angle and source radius
- ★ Final cut based on the Multivariate analysis (Boost Decision Tree)
- ★ Evaluation of the flux at different significance with unbinned method -> Max. likelihood method





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# E<sup>-2</sup> point-like sources

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discovery potential for point-like sources with a spectrum proportional to E<sup>-2</sup>



very large field of view

better w.r.t. IceCube in all the field of view at the same observation time

# Conclusions and outlook

- ★ First phase of KM3NeT implementation is fully funded and under way
- ★ Following phase (KM3NeT 2.0) to follow
- ★ KM3NeT/ARCA (≈ 1 km<sup>3</sup>) will be installed at the Italian node of the KM3NeT distributed infrastructure
- ★ Exciting physics prospects
  - Investigate the neutrino sky with unprecedented resolution and sky coverage



... and stay tuned... second part of KM3NeT tomorrow with KM3NeT-ORCA