# IceCube and CTA

**Multi-messenger high energy astrophysics**

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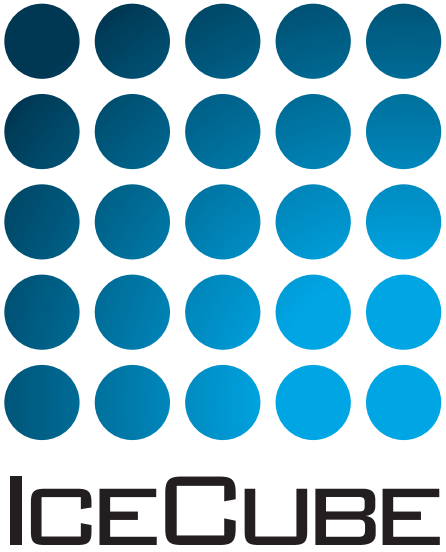



UNIVERSITÉ DE GENÈVE

Département de physique nucléaire et corpusculaire

Section de Physique

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

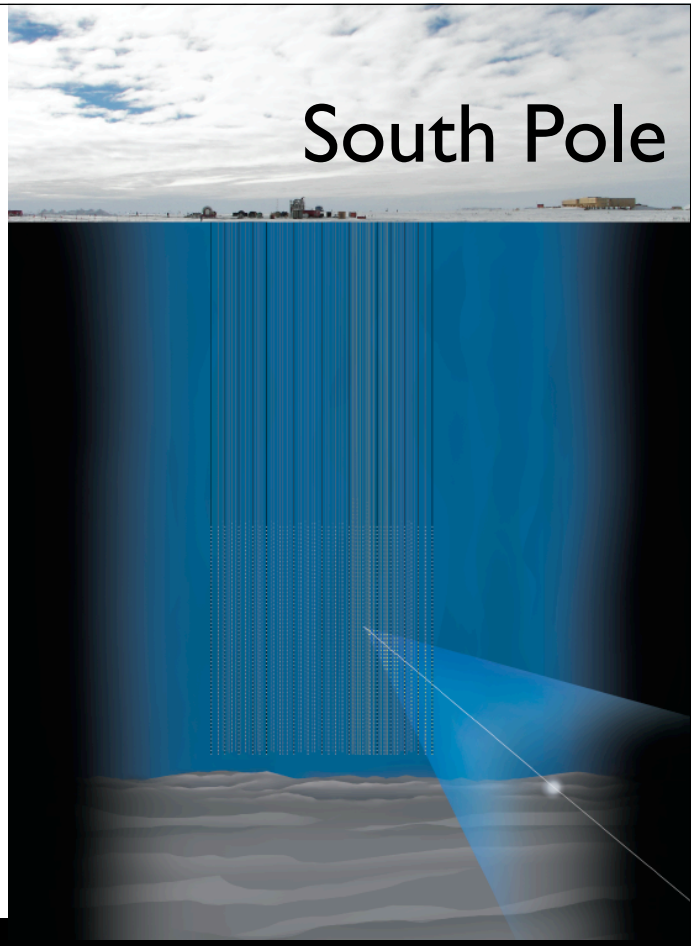
Collaboration with

ISDC


University of Zurich[UZH]

ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich

# High Energy Astrophysics from ground:



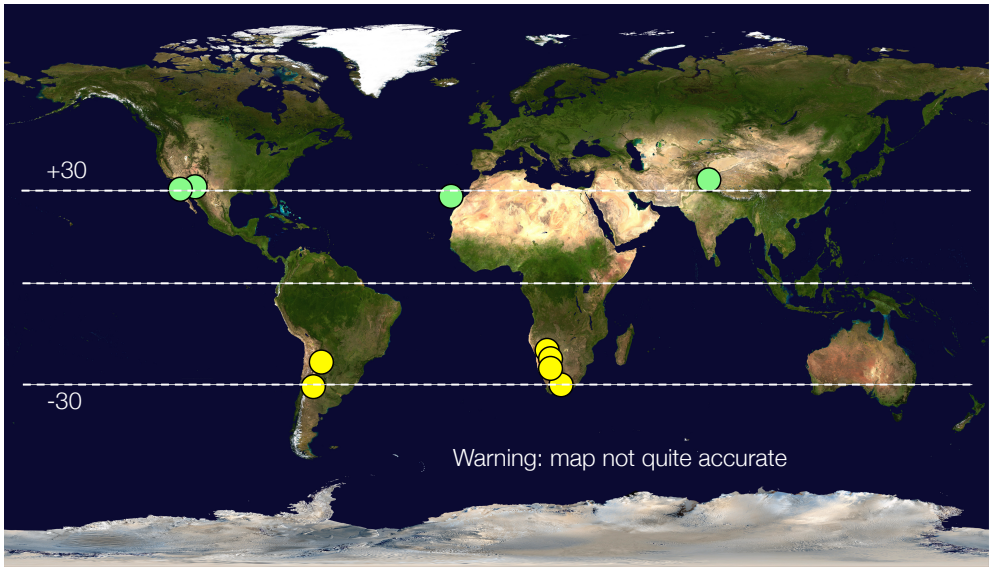

Middle-size (1 $km^2$) ground infrastructures =
200M$ scale projects
IceCube 250 scientists
CTA ∿1000 scientists
(800 FTE, 23 Swiss)

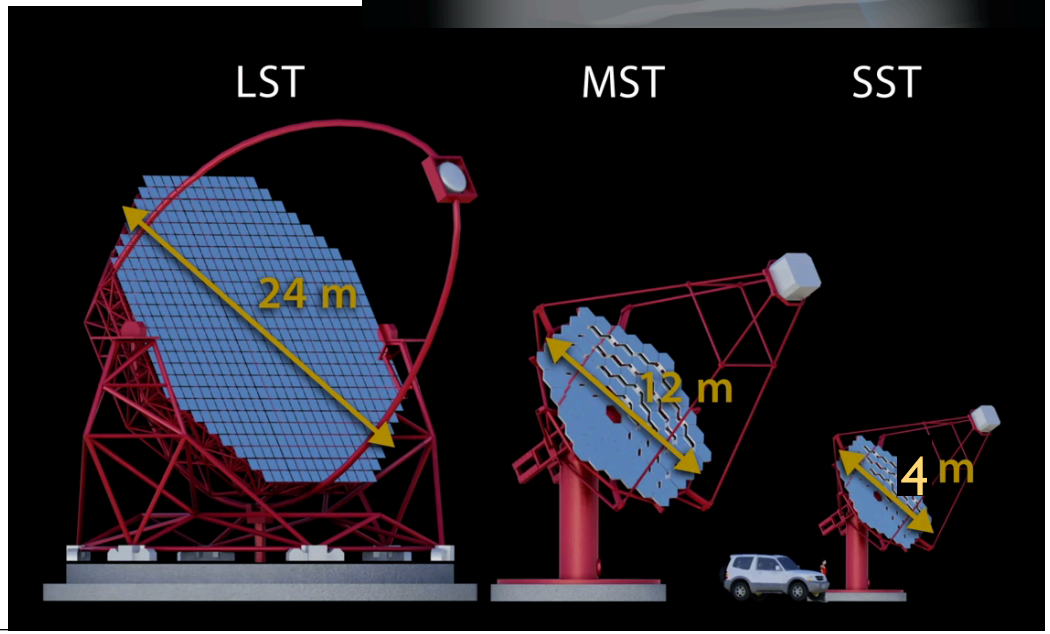
} worldwide

An observatory with O(100) telescopes in 2 Northern and Southern site

Sites under discussion

cta cherenkov telescope array



# What is astro/physics addressed by IceCube/CTA?

| Astrophysics | Particle Physics | Cosmology | Applied Science |
|---|---|---|---|
| Sources of CRs, gammas and neutrinos (SNR, molecular clouds, starbursts, mqso, unid, black hole jets, GRBs, galactic plane) | Neutrino mass matrix (oscillations) | Dark Matter | South Pole climate |
| Cosmic ray anisotropies (local sources, galactic magnetic fields) | Neutrino x-section at UHE | Cosmogenic neutrinos, evolution of galaxies, primordial sources | Glaciology |
| Cosmic Ray composition at transition between galactic/ extragalactic | Violation of Lorentz Invariance | | Earth density profile tomography |
| SN explosion Monitoring (also hierarchy and theta_13)<br>Solar flare Monitoring<br>Stellar interferometry | Sterile neutrinos & mass hierarchy with low energy extensions | | reversible cameras to generate energy during the day with a Stirling engine or multi-junction cells so to have a C02-neutral telescope array.  |

Icecube in Nature 484, April 2012 (challenge GRBs as UHE cosmic ray sources)

17 published in 2012 (+ 8 in preparation); 15 published papers in 2011; 13 published in 2010

10 in 2009

About 74 in total (including AMANDA)

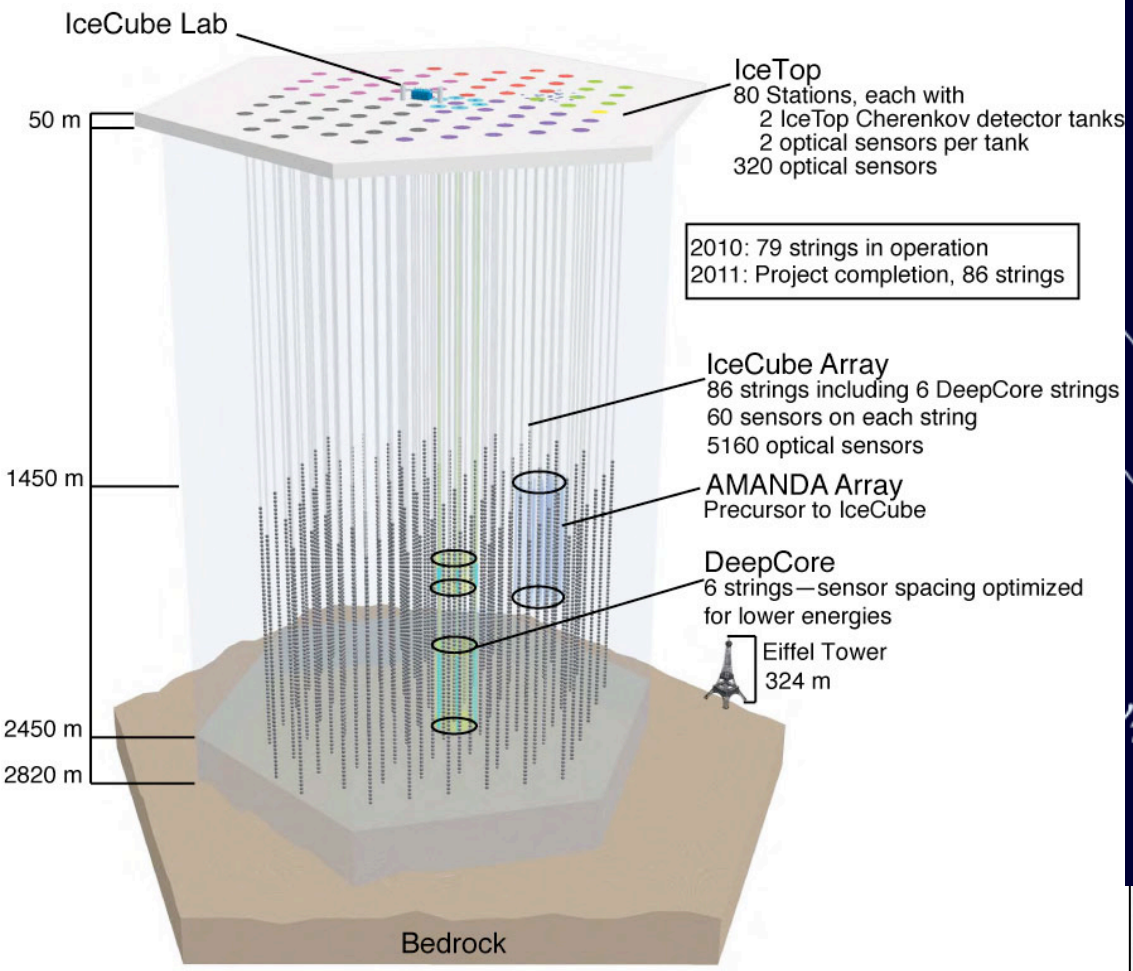
# ICECUBE

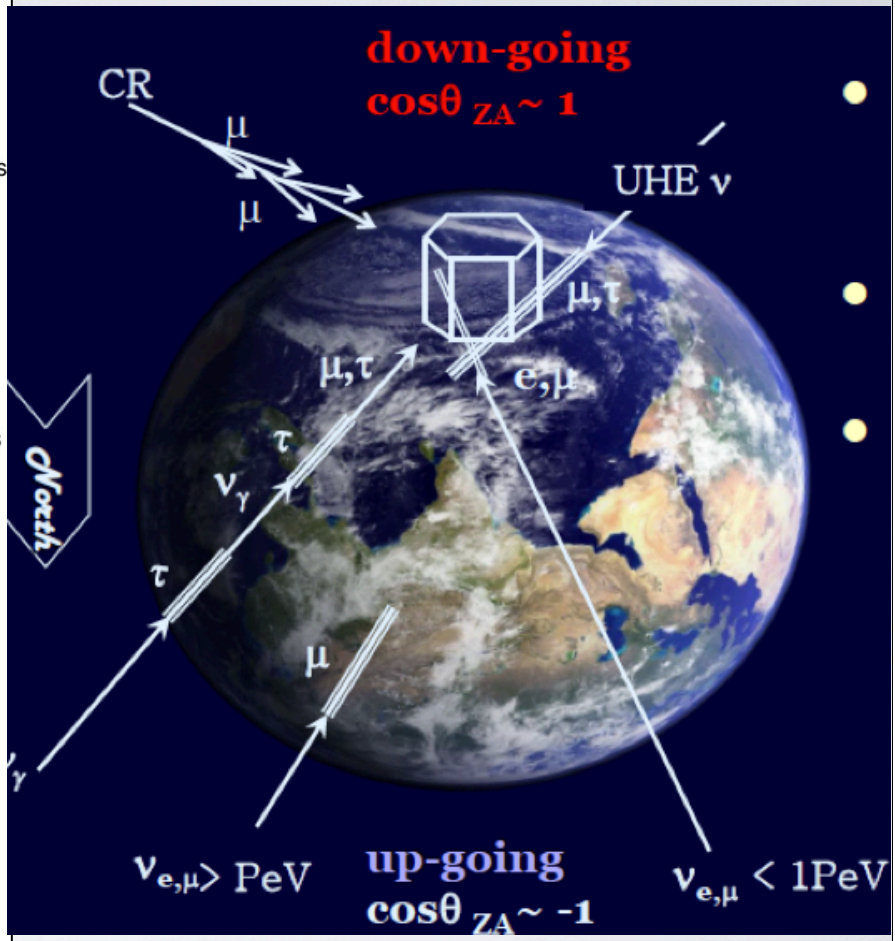
IceCube 79 (2010-11)

IceCube 86 (2011-13)

UHE unblinded for 2010-11

Point source unblinding just done by UNIGE



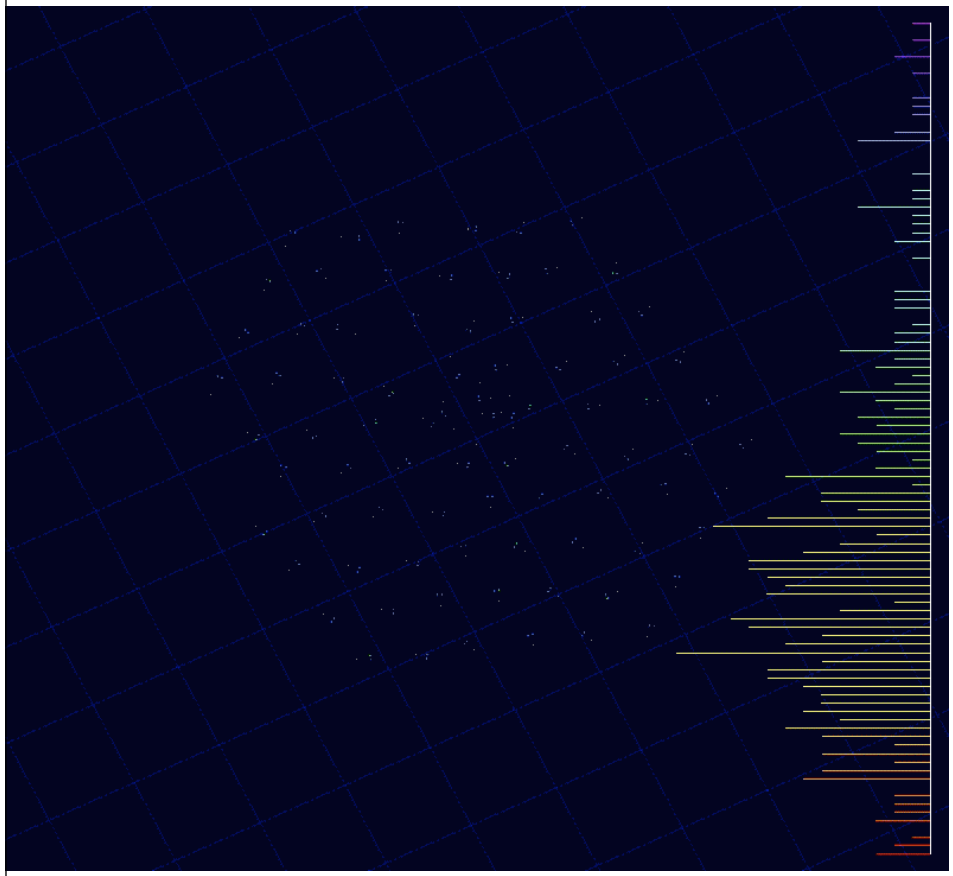

Completed in January 2011 on schedule and with 6 more strings

EHE data analyzed and presented at Neutrino 2012

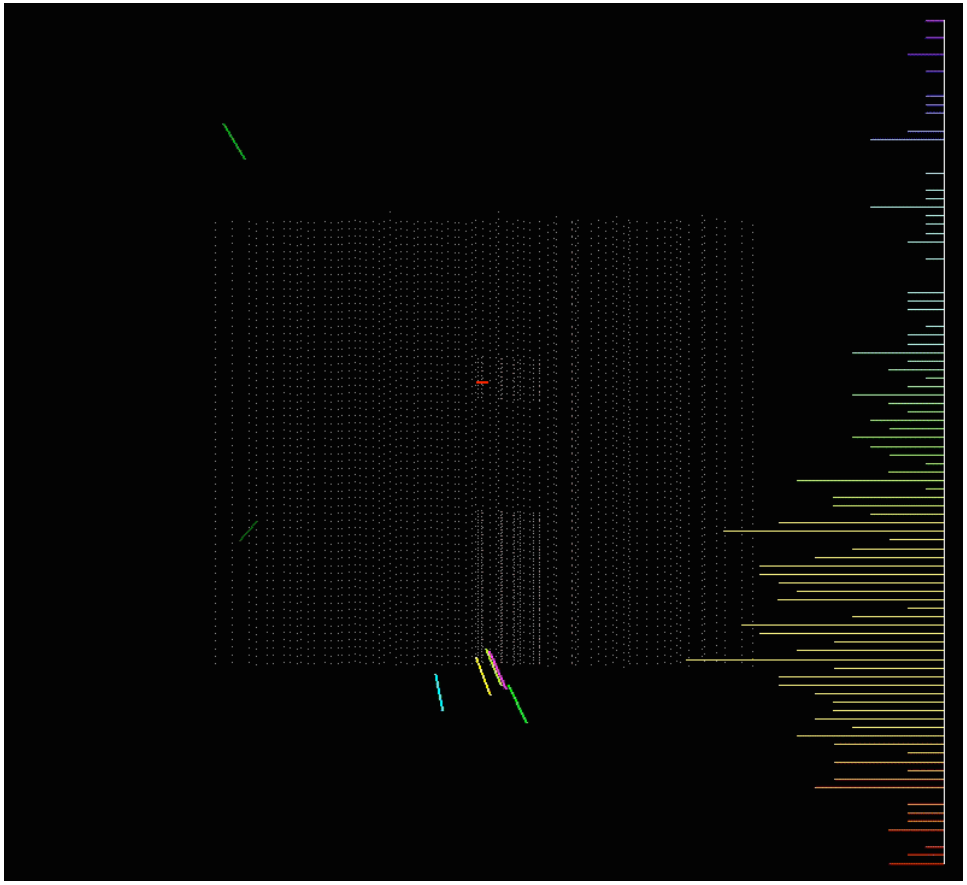
# Events in a km3-detector: PeV energies

To be able to see UHE events and reasonable statistics for low-luminosity beams

Run119316-Event36556705
Jan 3rd 2012
NPE $9.628 \times 10^4$
Number of Optical Sensors 312



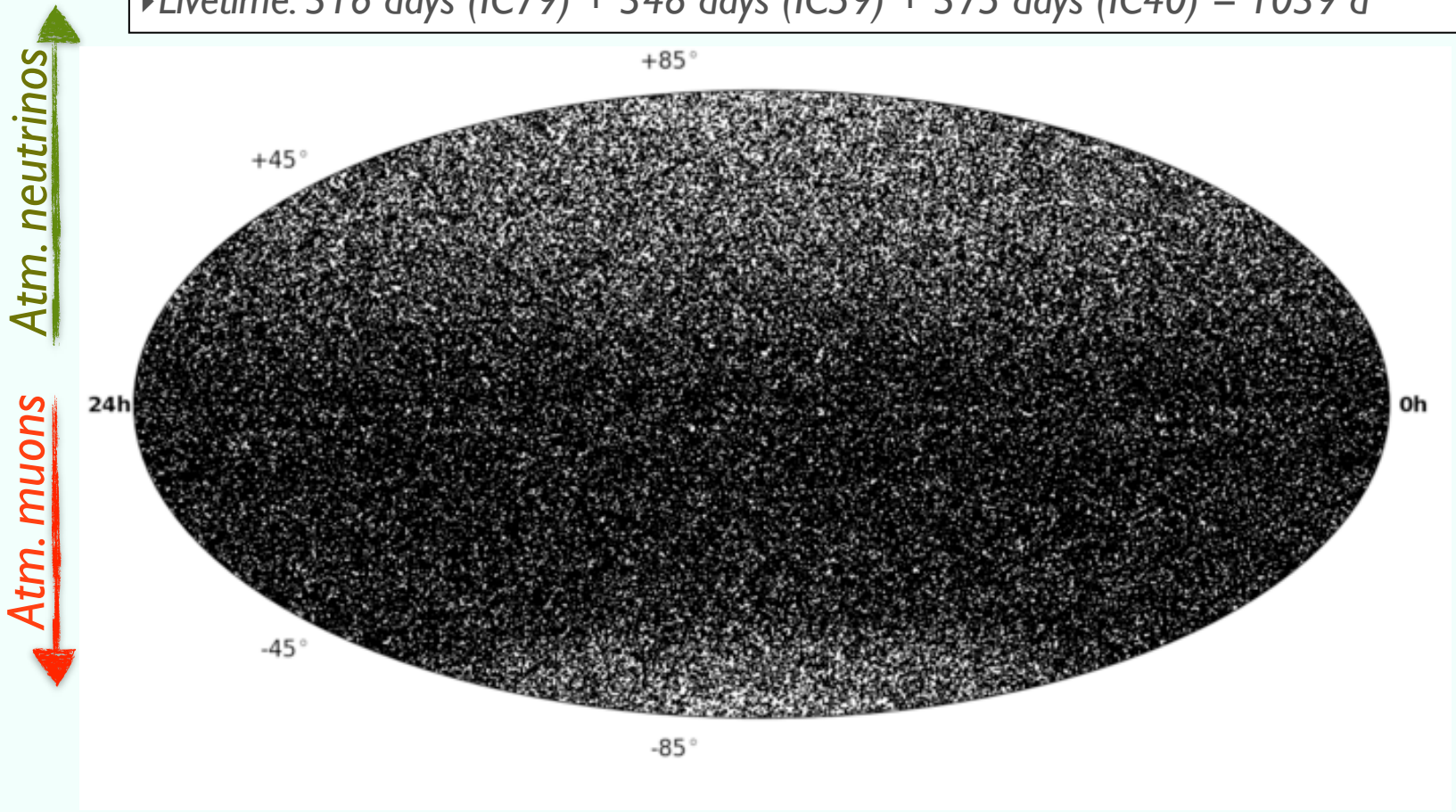
Run118545-Event63733662
August 9th 2012
NPE $6.9928 \times 10^4$
Number of Optical Sensors 354



2 events / 672.7 days - background (atm. m + conventional atm. n) expectation 0.14 events preliminary p-value: 0.0094 (2.36σ)

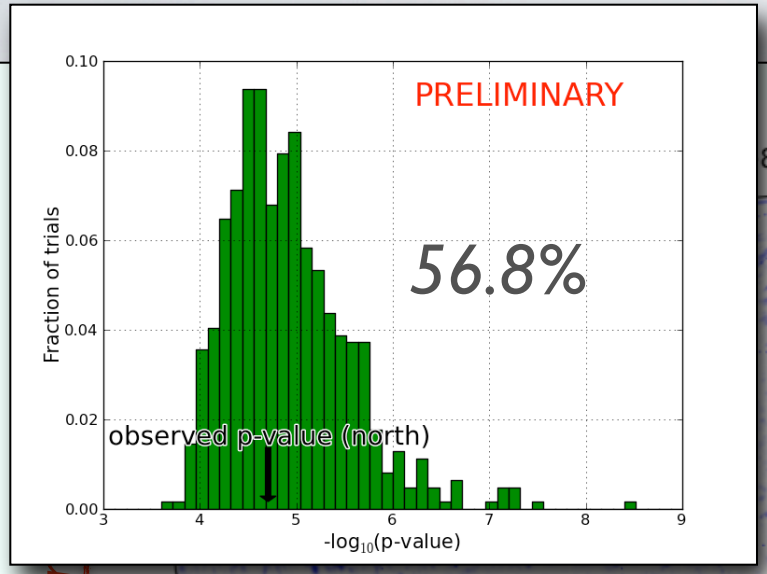
# 3 YR SKYMAP

- *Total events (IC40+IC59+IC79): 108317 (upgoing) + 146018 (downgoing)*
- *Livetime: 316 days (IC79) + 348 days (IC59) + 375 days (IC40) = 1039 d*




JA Aguilar, UniGE, Now 2012

# 3YR SKYMAP


PRELIMINARY
56.8%
observed p-value (north)
Fraction of trials
-log10(p-value)


85°
0h
-85°
-log10(p) = 4.707
Ra: 34.25
Dec: 2.75
nSrcbest: 23.07
γbest: 2.35
-log10(p) = 4.047
Ra: 219.25
Dec: -38.75
nSrcbest: 20.81
γbest: 3.75
Atm. muon
0.0
0.6
1.2
1.8
2.4
3.0
-log10 p

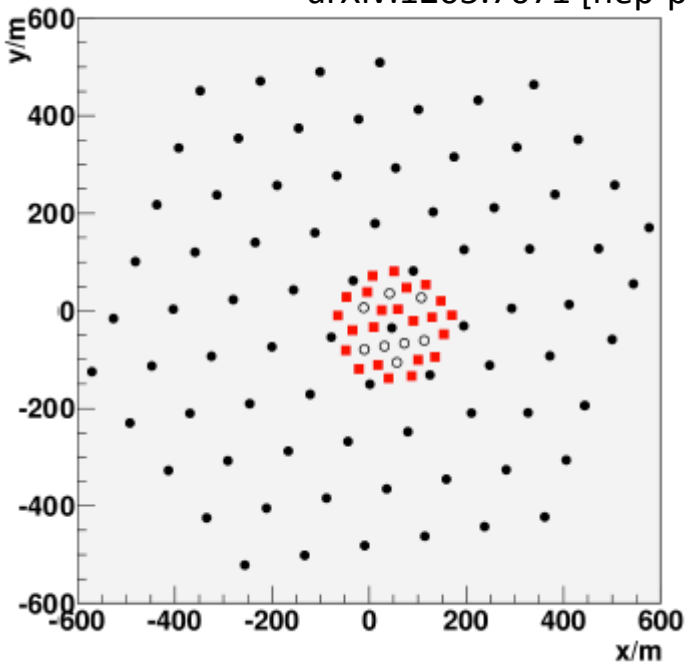

PRELIMINARY
97.9%
observed p-value (south)
Fraction of trials
-log10(p-value)

# SN NEUTRINOS AND PINGU

● : IceCube
○ : DeepCore
■ : Deep and Dense

20 strings
120 sensors/string
3 meter between sensors
4π sensitive sensors

arXiv:1205.7071 [hep-ph]





The luminosity and average energy are entangled, and cannot be distinguished by just measuring the rate !

Flux at detector $\frac{d\tilde{\Phi}_{\bar{\nu}_e}}{dE_\nu}(E_\nu, d) = \frac{1}{4\pi d^2}\int_0^{\tilde{t}} \frac{L(t)}{\langle E\rangle(t)} f_{\alpha(t),\langle E\rangle(t)}\, dt$

Luminosity

Average energy

Spectral shape
In this talk we use:

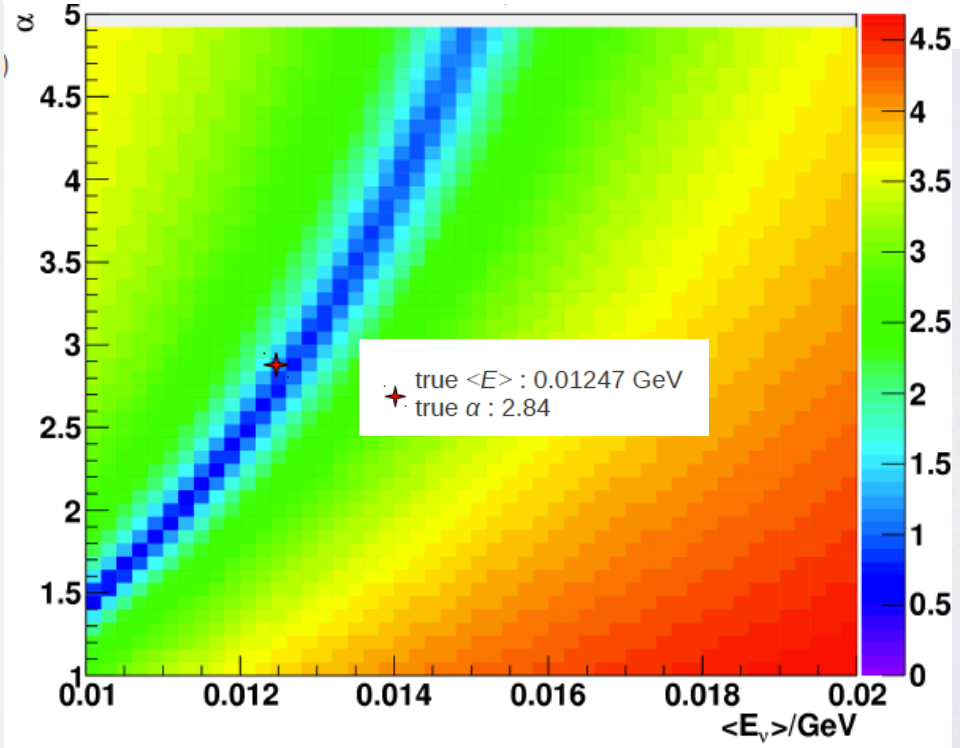
$f_{\alpha,\langle E_\nu\rangle}(E_\nu) = \frac{(1+\alpha)^{1+\alpha}}{\langle E_\nu\rangle \Gamma(1+\alpha)}\left(\frac{E_\nu}{\langle E_\nu\rangle}\right)^{\alpha} e^{-(1+\alpha)\frac{E_\nu}{\langle E_\nu\rangle}}$

Average energy

$\log(\chi^2)$

'Shape'

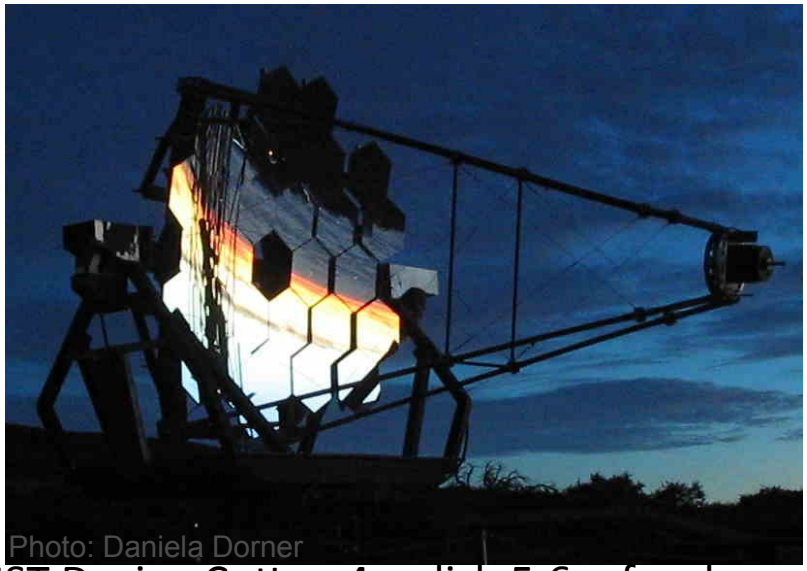
coincident hits allow to disentangle energy spectrum of neutrinos from SN collapse at 10 kpc



# CTA small telescopes (SSTs)

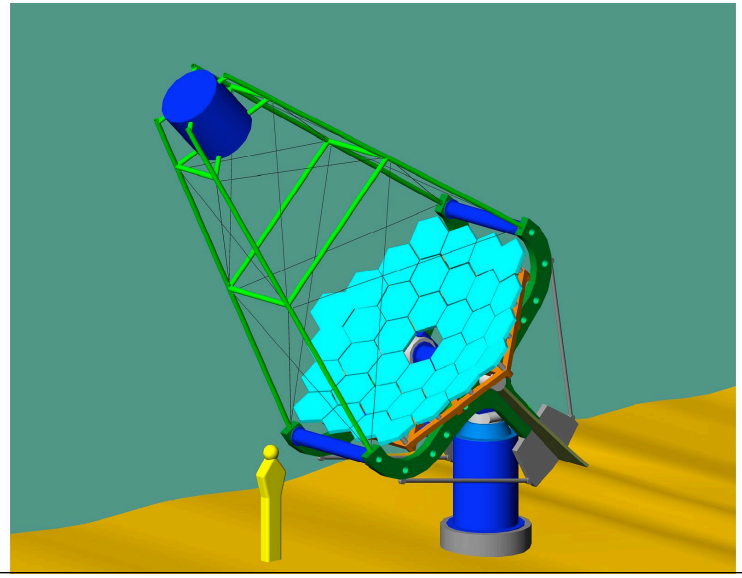
out-trigger system of abt 70 telescopes to achieve the required sensitivity (0.01-1 Crab in 50 hrs @ 5σ) between 3-100 TeV: cost constrain about 450k/SST

FACT with G-APD camera (ETHZ, EPFL,UniGE)



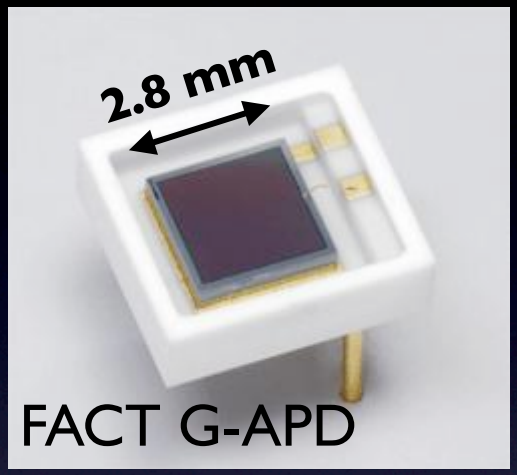

SST Davies-Cotton 4m dish 5.6m focal
f/D = 1.4 and FoV = 9-10°
Project lead by UniGe. UniGE, UniZH, ETHZ, EPFL involved in camera construction

Discovery sectors: < 50 GeV (Large-Size Telescopes for GRBs, pulsars, DM); > 5 TeV (Small-Size Telescopes).
SSTs:
- hadronic acceleration - connects to neutrinos (multimessenger), BH jets and shock diffusion
- unid PeVatrons sources of CRs in the knee and above
- EBL (informs us on cosmological distribution of sources), intergalactic magnetic fields,
- new physics (VLI).

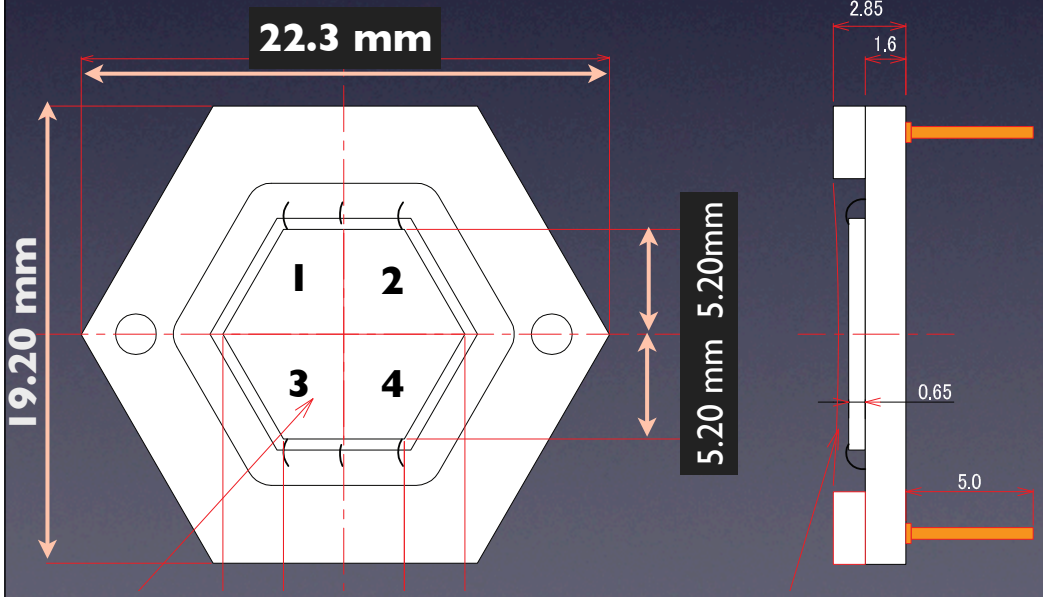


# The Geiger-APD detectors

Custom design from Hamamatsu to avoid square to hexagon adaptation of the light concentrators




R&D Hamamatsu-DPNC



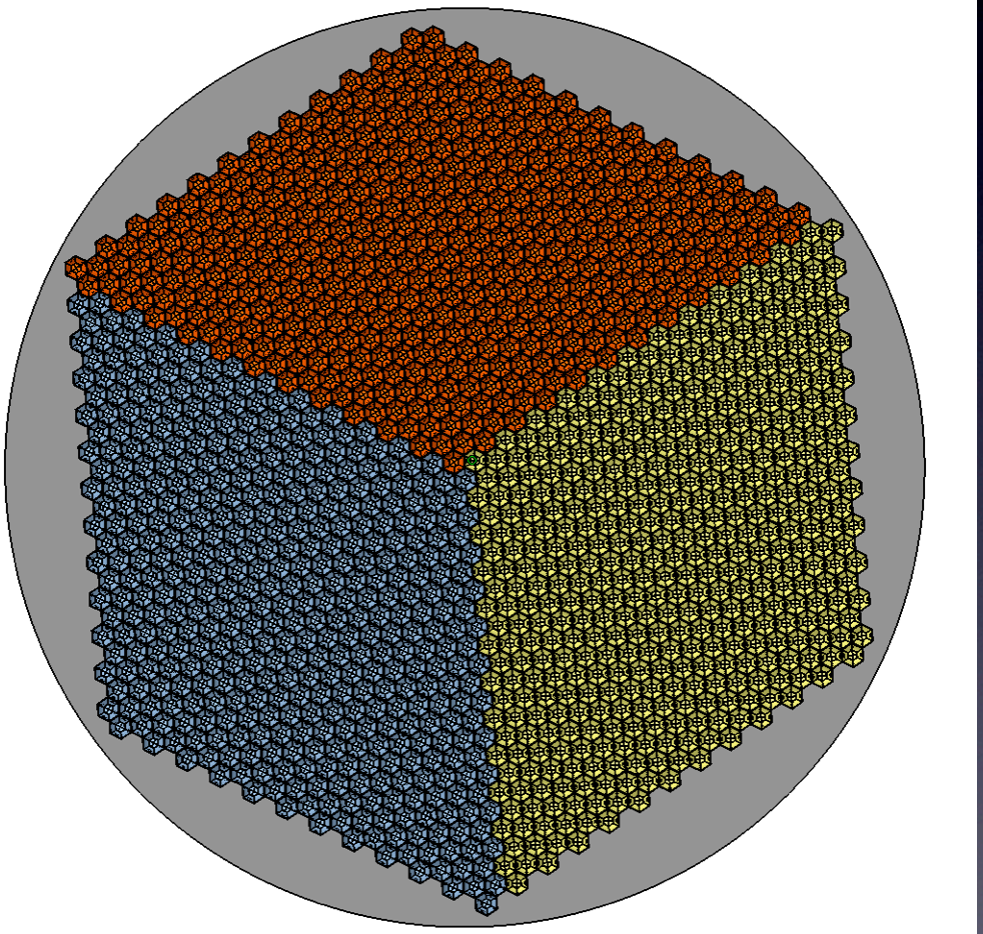

**G-APDs features:**

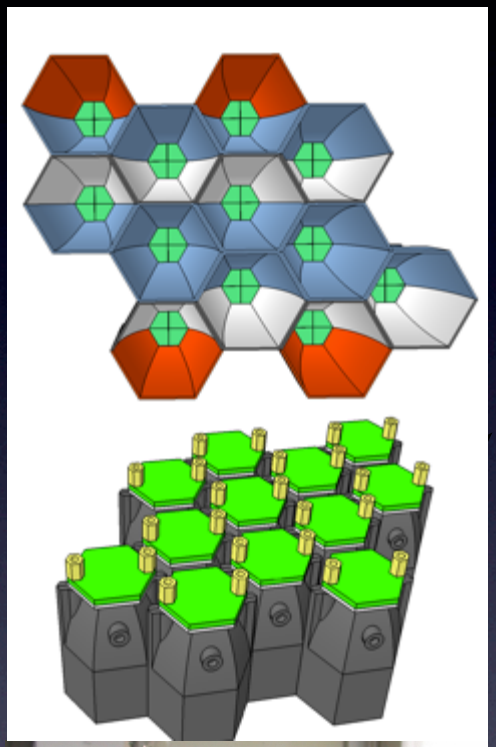
- Good PDE > 25% integrated between 300<λ/nm<650 (50 μm);
- Excellent s.p.e. discrimination;
- Large Dark Count rate (but << NSB);
- Crosstalk (about 12% at nominal voltage, can be reduced with trenchers);
- Single devices match the required SST pixel size (0.25o, d=2.5 cm) with light concentrators (open funnel hex-to-hex possible);
- Low operating voltage, robust (survive direct exposure to sunlight, aging);
- Lightweight camera: simplified support structure.
- Industrial production of detector plane + camera

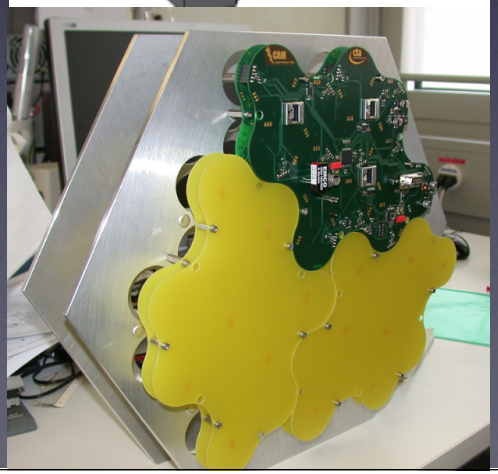
# Evolution of Camera design

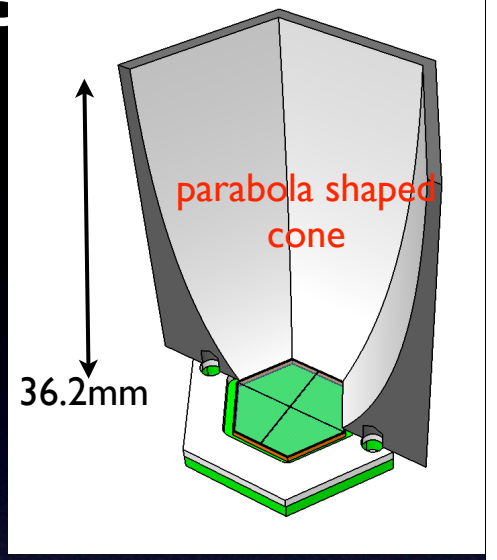
1296 pixels/ 108 modules of 12 pixels
10.4mm ⇨ 23.1mm s side-to-side hex-to-hex

88cm inner circle diameter

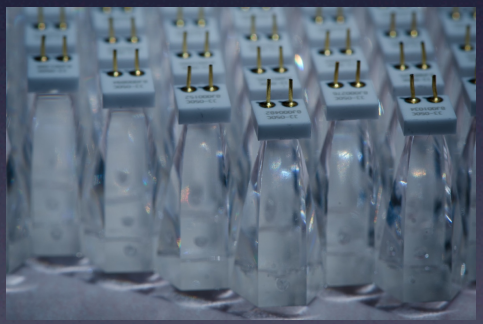


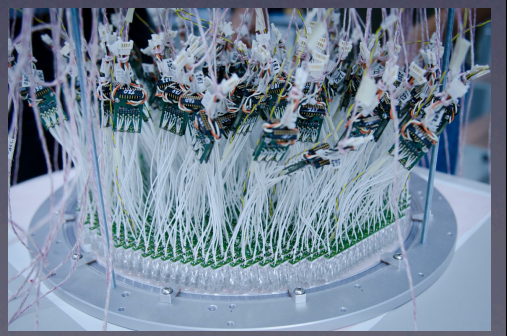




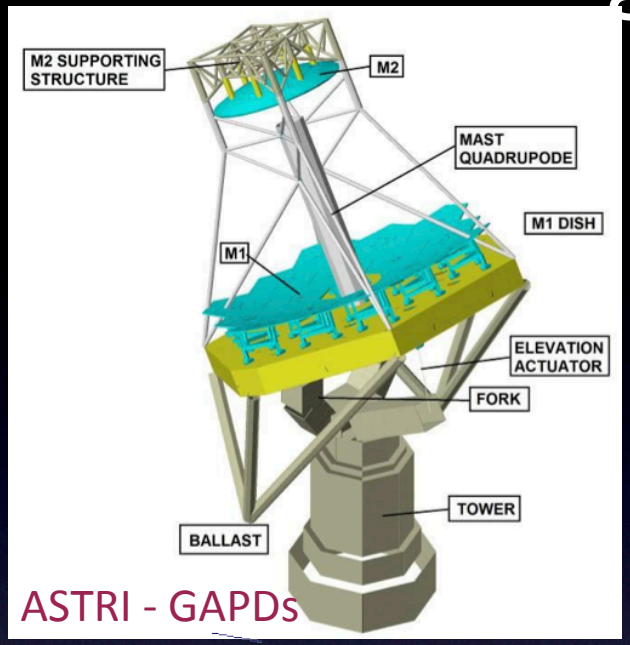



FACT: 1440 channels
40 cm diameter, 4.5 deg FoV
2.8mm ⇨ 1 cm square-hex funnel





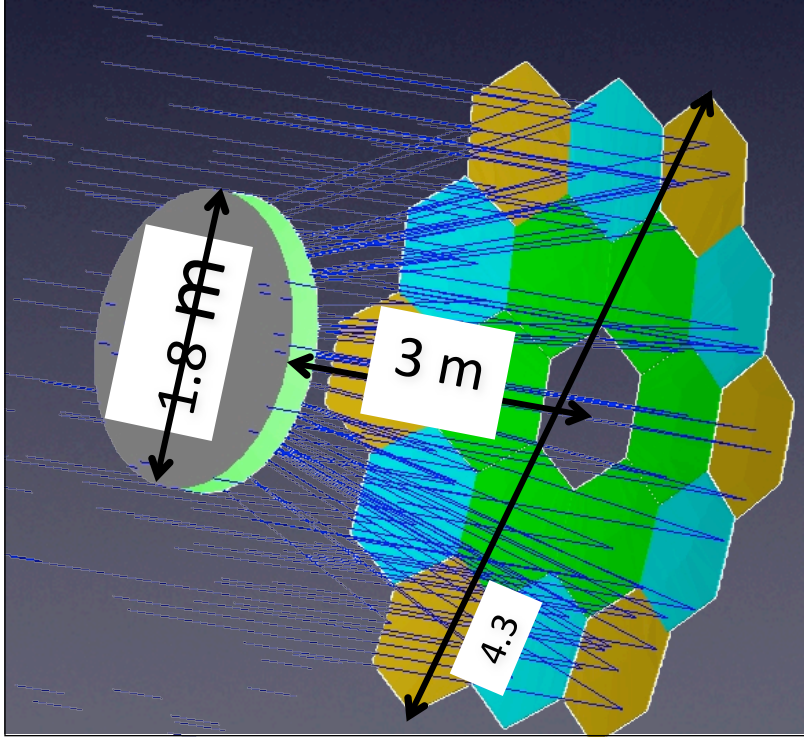
# Other SST design telescopes: Swartzchild-Couder




ASTRI - GAPDs

GATE - MAPMT camera

5 telescopes funded with 8M by Italy.
Challenge: cost, mirrors and structure but potentially can achiev better ang. res.
Healthy competition, but time scale for decision of the project is 2 years. Array in 2015 as seed of CTA.



# Conclusions

- Multi-messengers astrophysics with gammas and neutrinos represented in Switzerland by participants to IceCube, CTA, MAGIC and FACT
- CTA: construction of an SST -DC prototype in 2-3 years with Germany, Poland, Austria, Argentina. Switzerland is involved in innovative camera based on G-APDs. New partners are welcome.
- IceCube is proposing extensions to low energies valuable for DM, SN collapse, neutrino fundamental properties, sterile neutrinos