Instrumentation for Astroparticle Physics

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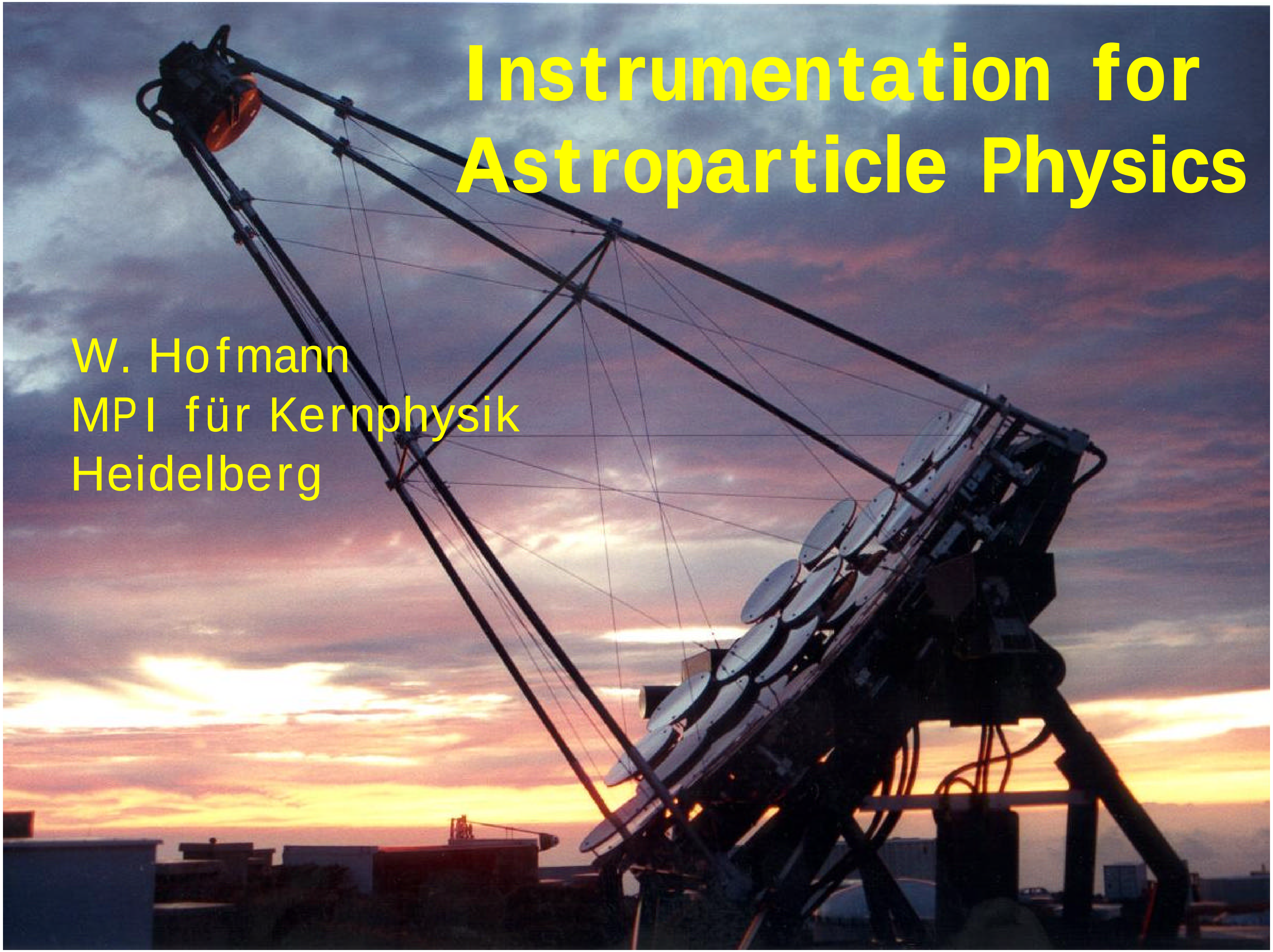
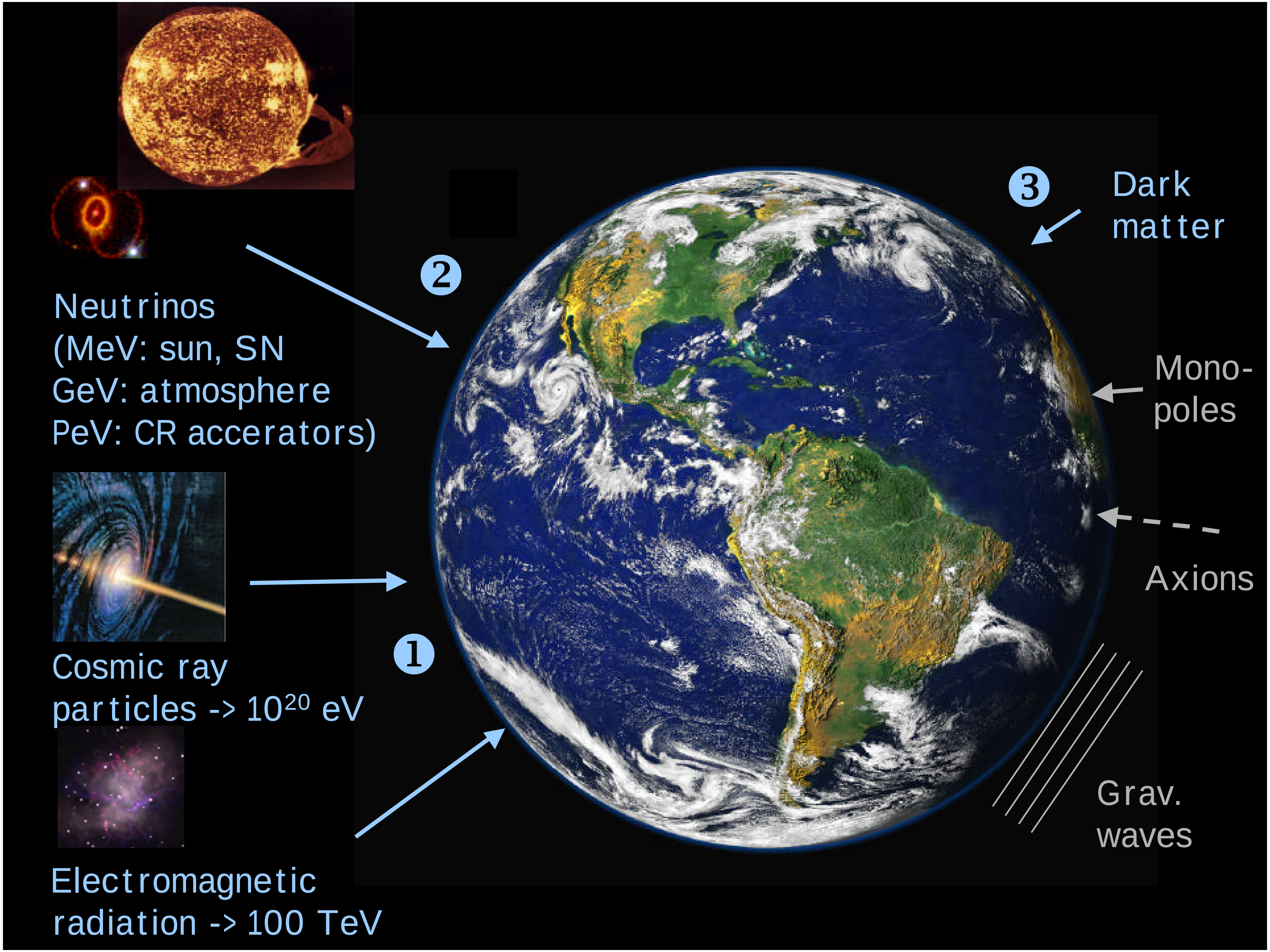
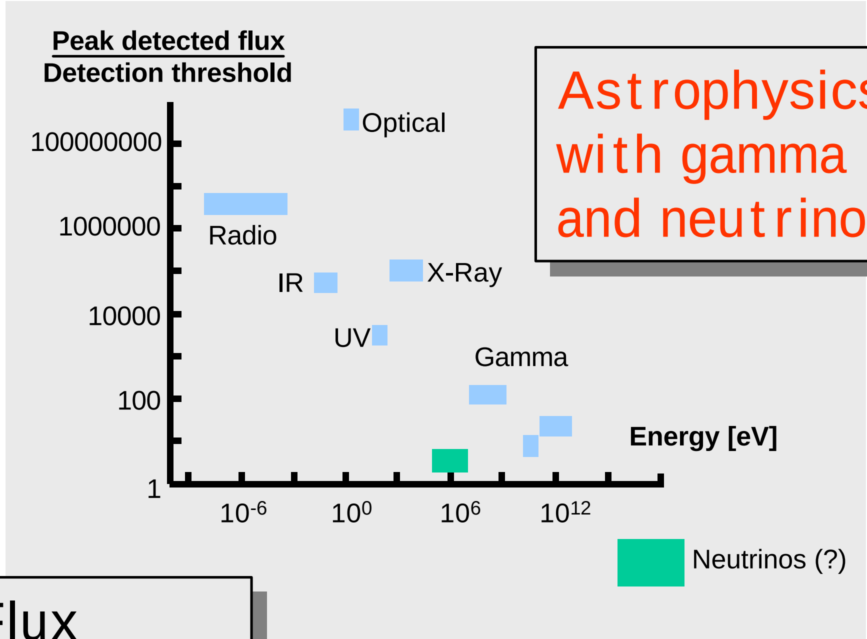




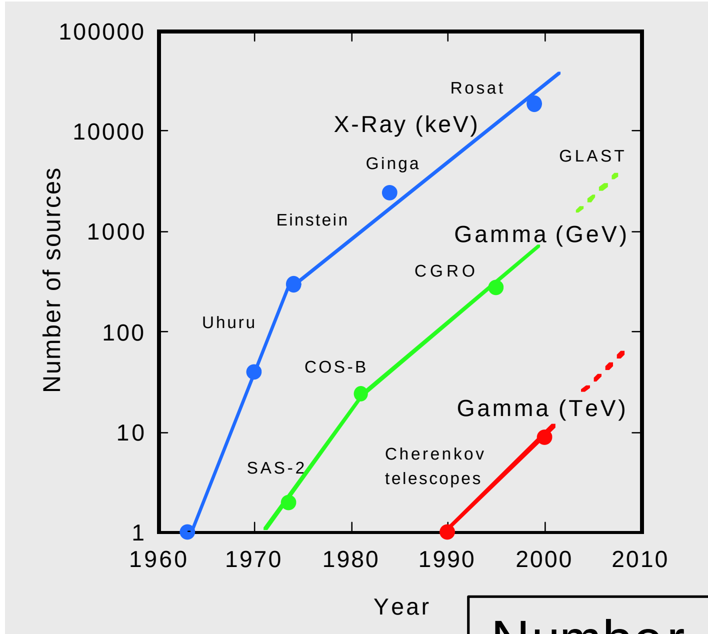
Neutrinos
(MeV: sun, SN
GeV: atmosphere
PeV: CR accerators)
2
Cosmic ray
particles -> 10^{20} eV
1
Electromagnetic
radiation -> 100 TeV
3
Dark
matter
Mono-
poles
Axions
Grav.
waves

State of the field: a charming infant

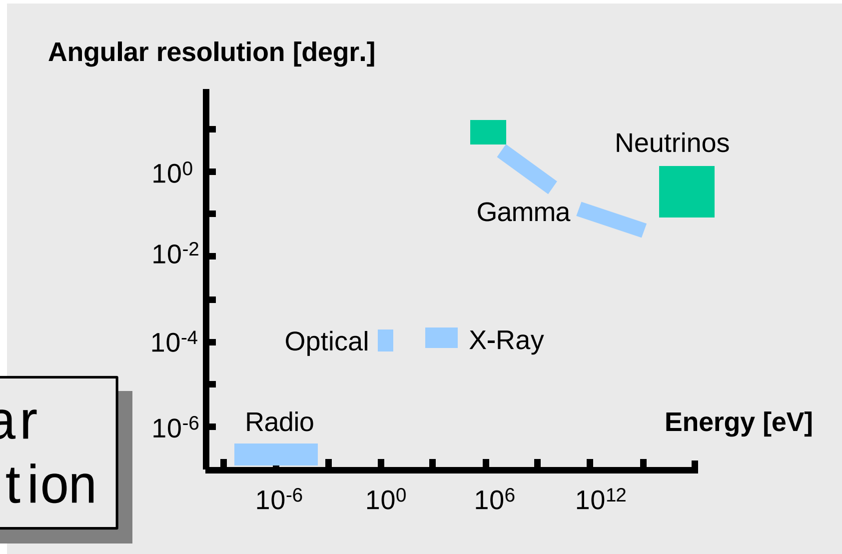


Astrophysics with gamma rays and neutrinos

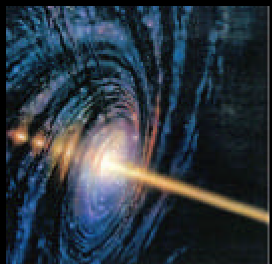
Flux sensitivity



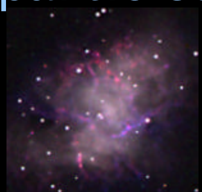
Number of sources



Angular resolution

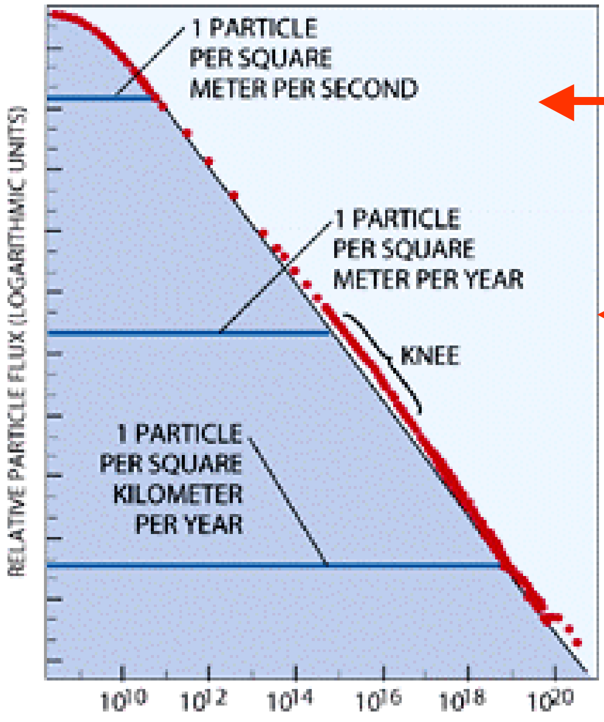


Cosmic ray
particles -> 10^{20} eV



Electromagnetic
radiation -> 100 TeV

The big issues in cosmic-ray physics

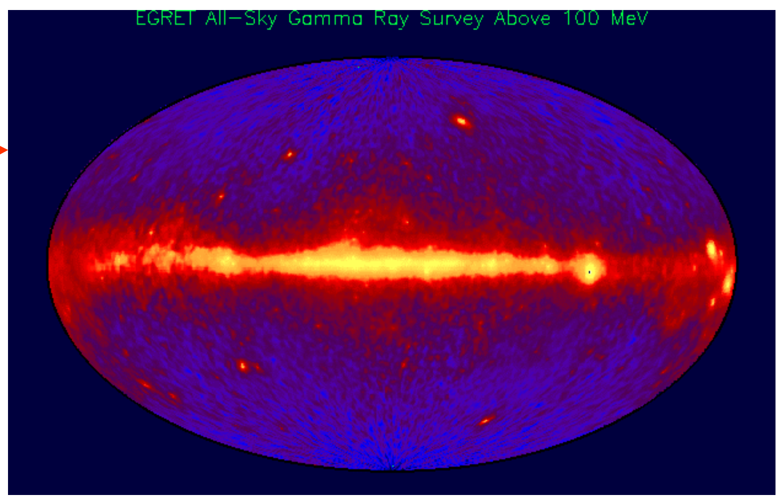


eV

- at low (GeV – TeV) energy:
  antiparticles in cosmic rays?
  AMS
- at medium (PeV) energy
  elemental composition, change in composition at knee?
  (KASKADE,...)
- at high (EeV) energy
  spectrum, particles beyond GKZ cutoff?
  AUGER

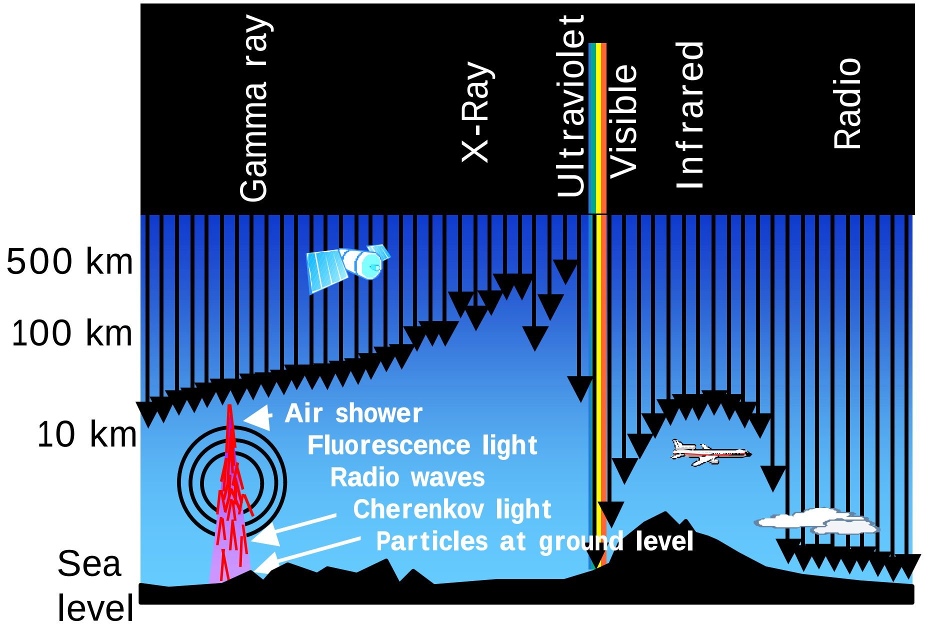
- Sources of cosmic rays
  traced in the light of (secondary) gamma rays

γ-yield = CR density x target density



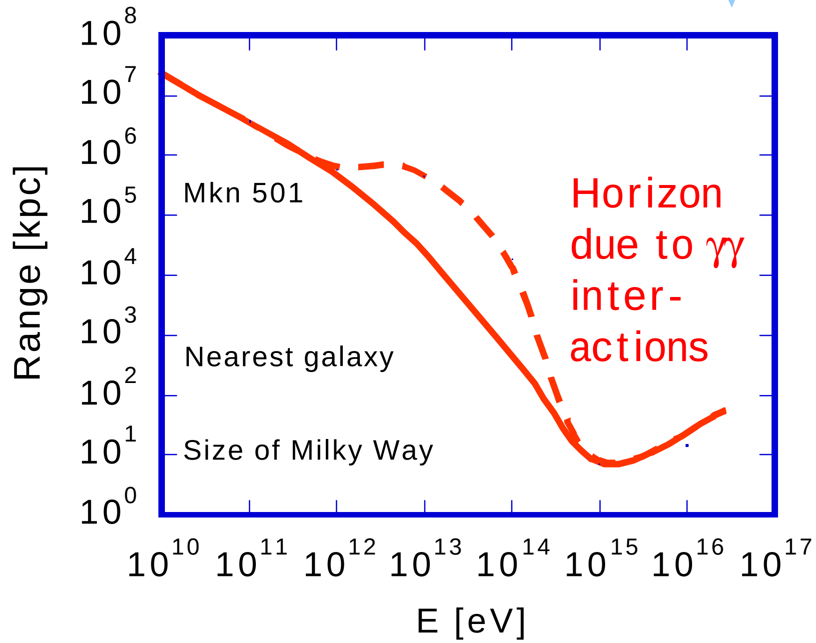
EGRET
~ 100 MeV

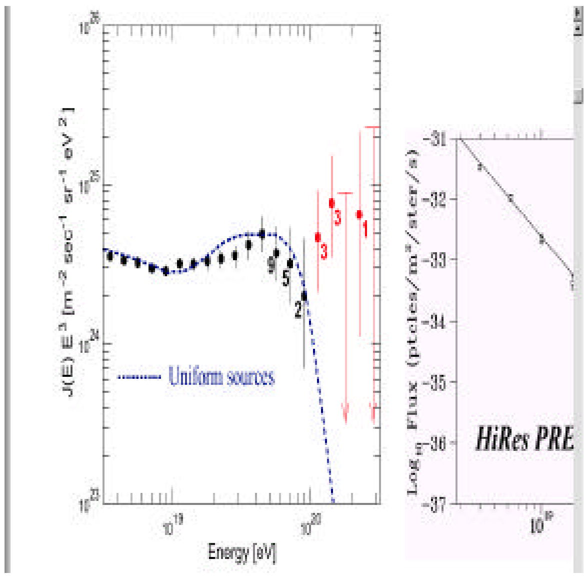
Propagation of electromagnetic radiation



In the Earth's atmosphere

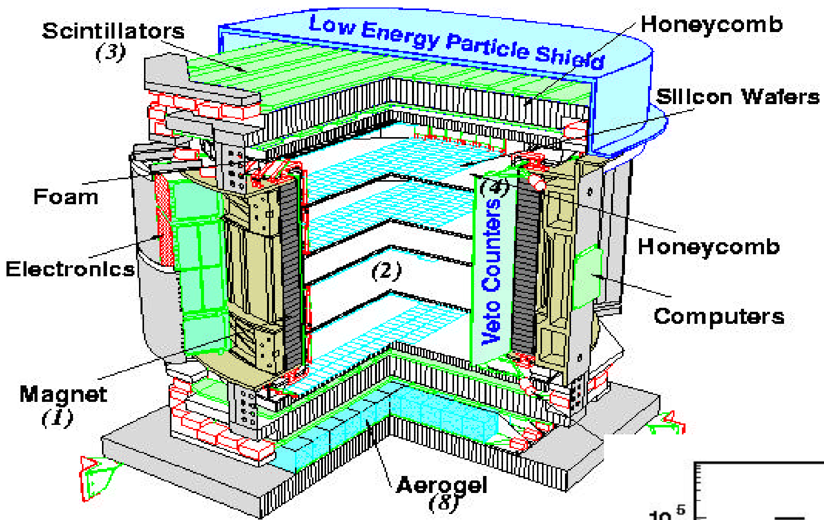
In space



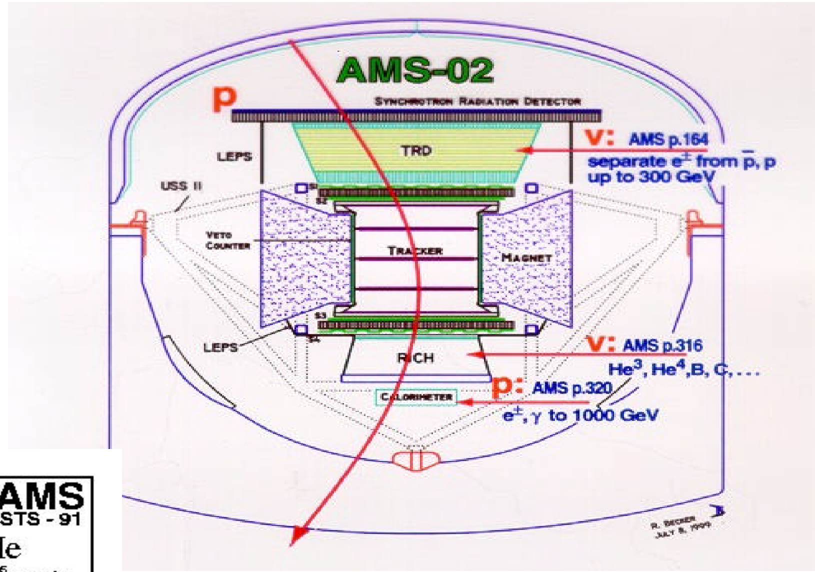


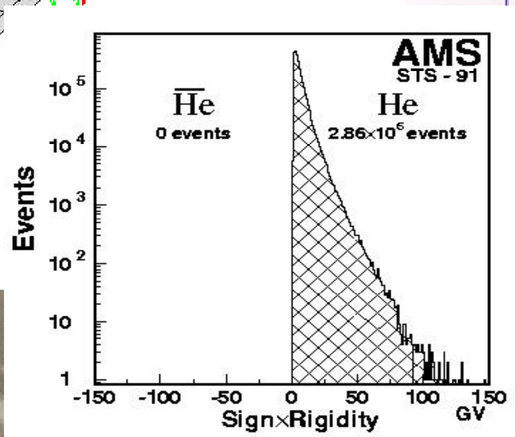
similar effect:
Cosmic-ray propagation
cuts off at 10^{20} eV

GeV/TeV CR: Alpha Magnetic Spectrometer

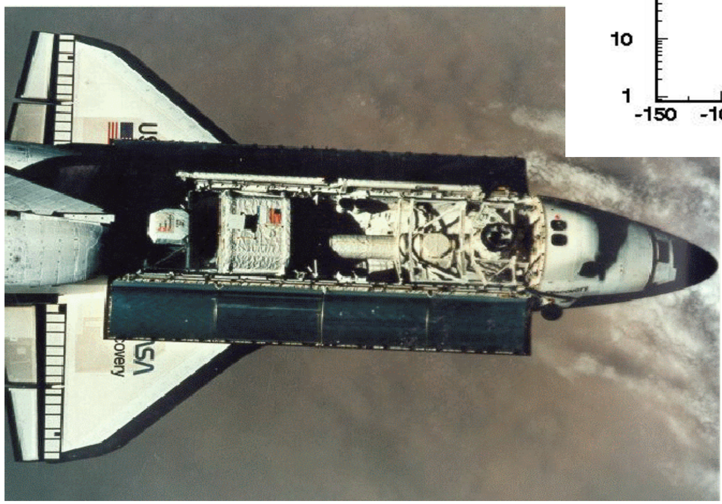


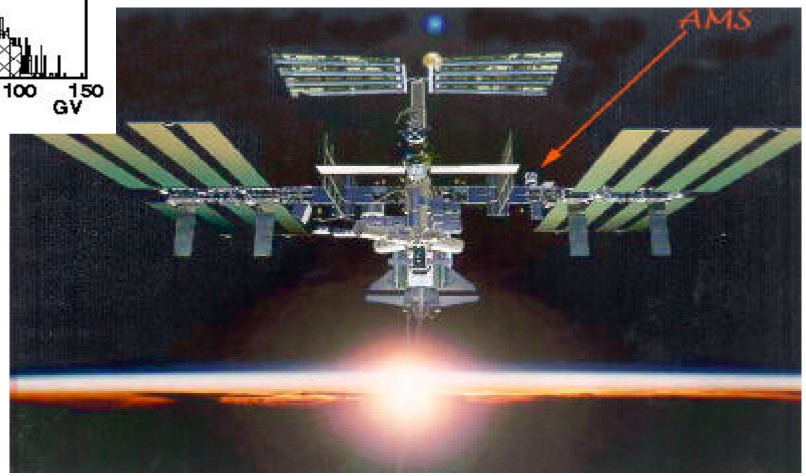
AMS-01 (1998)



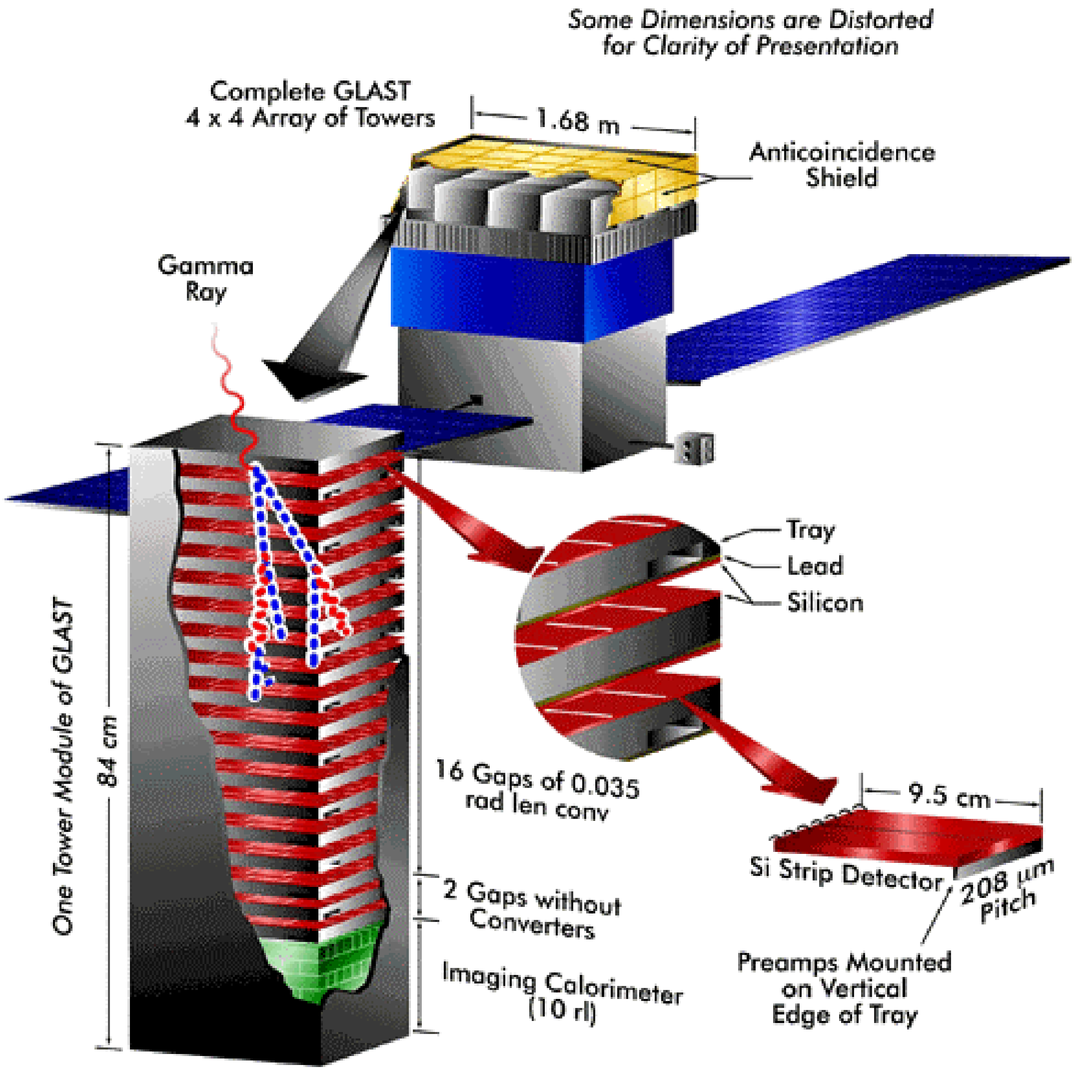


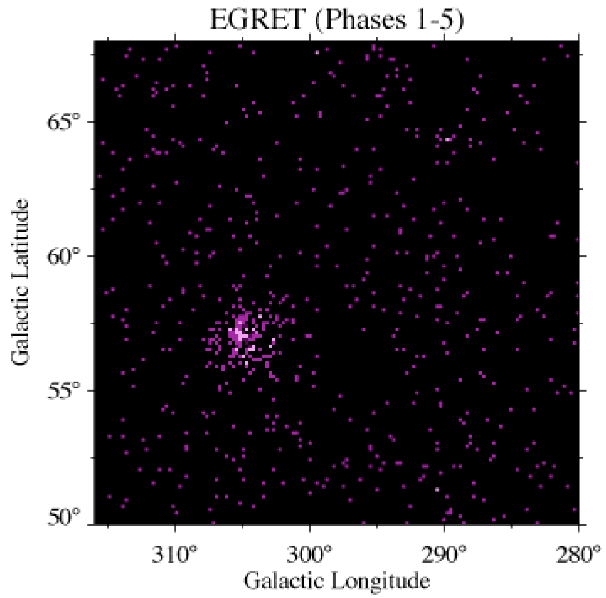
AMS-02 on ISS

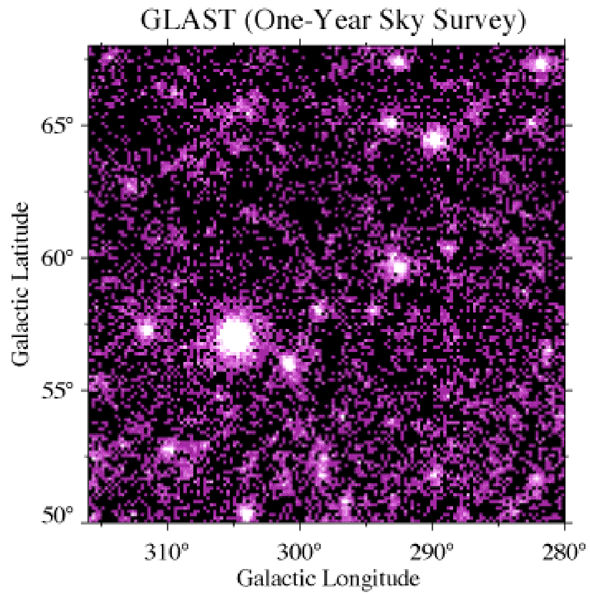




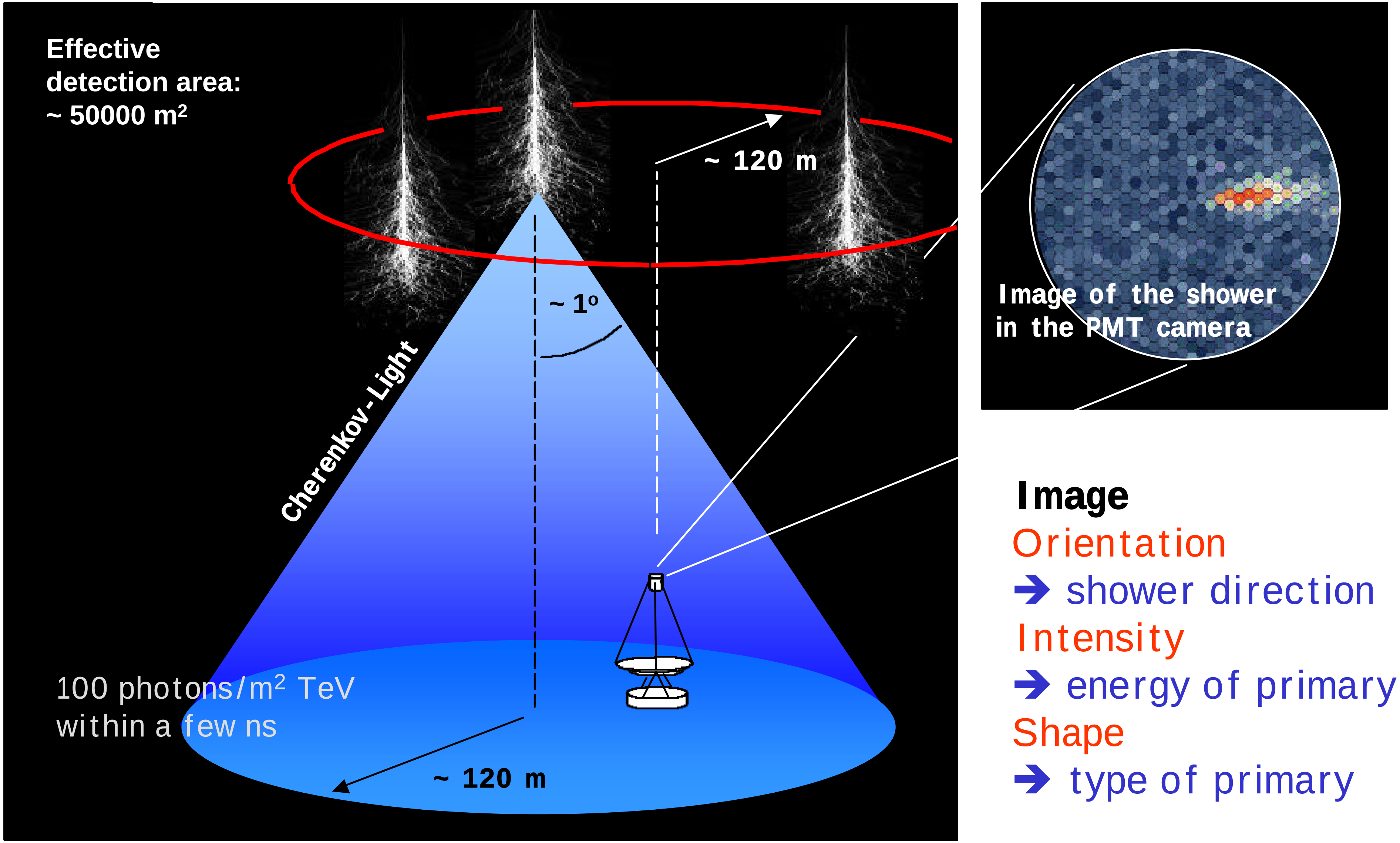
GLAST: γ-rays in the GeV energy range







VHE air shower detectors: Cherenkov telescopes



Image

Orientation

➔ shower direction

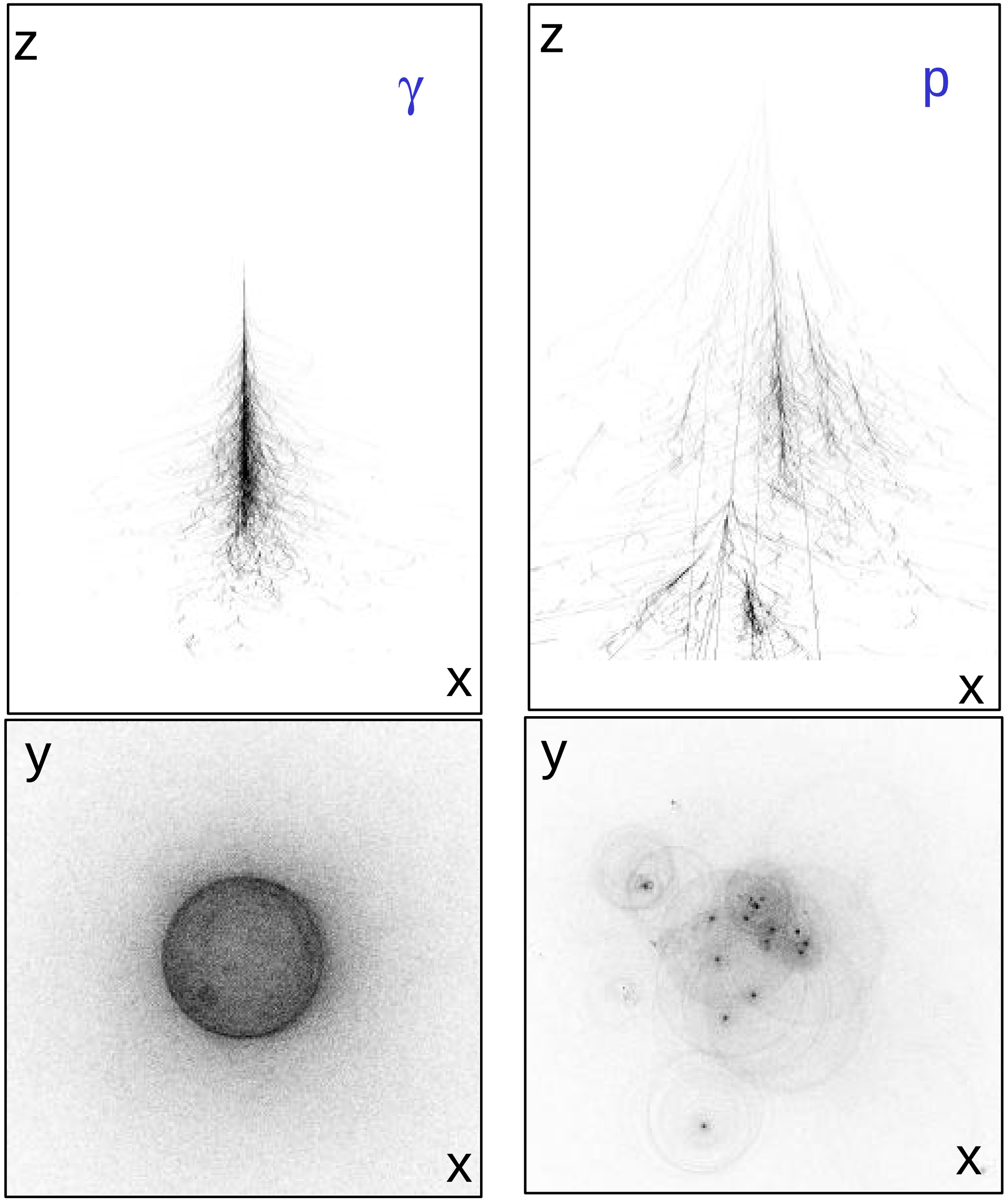
Intensity

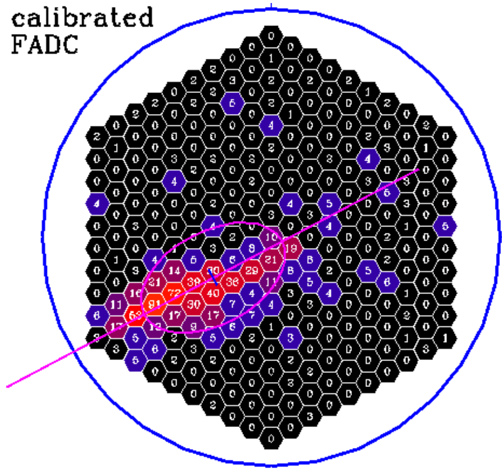
➔ energy of primary

Shape

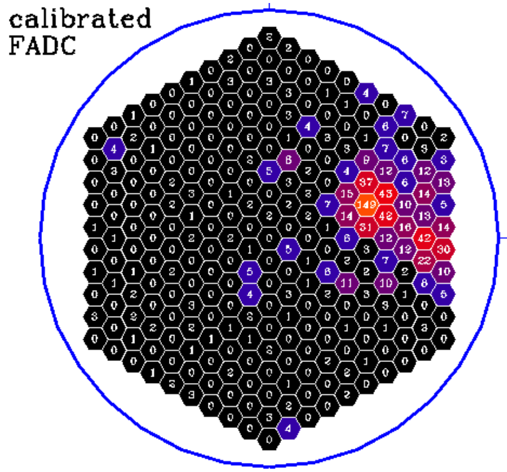
➔ type of primary

Telling γ-rays from hadronic cosmic rays





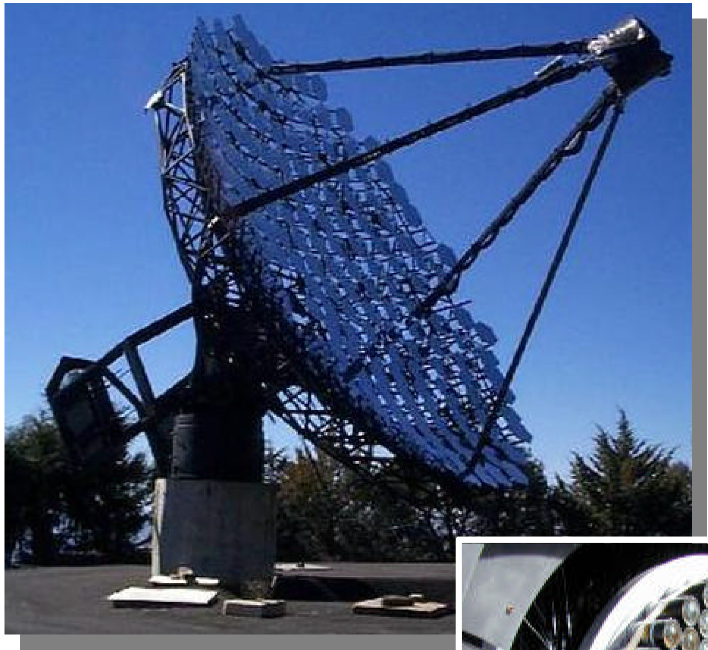
γ (?)



p (?)

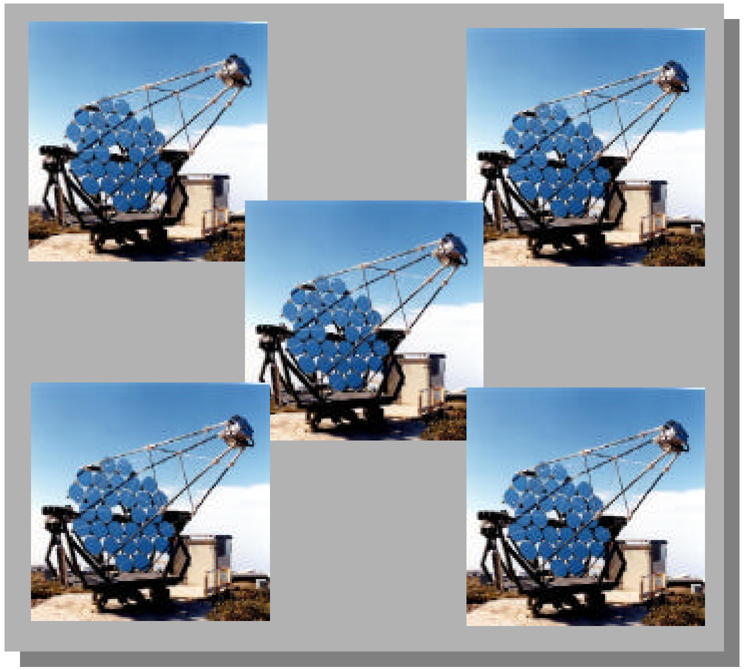
The imaging atmospheric Cherenkov technique

Pioneered by the WHIPPLE group



Perfectioned in CAT telescope

Stereoscopy with HEGRA



WHIPPLE 490 PMT camera

Four eyes see better than one: H.E.S.S.

(and VERITAS, CANGAROO, ...)

12 m Cherenkov telescopes under construction in Namibia

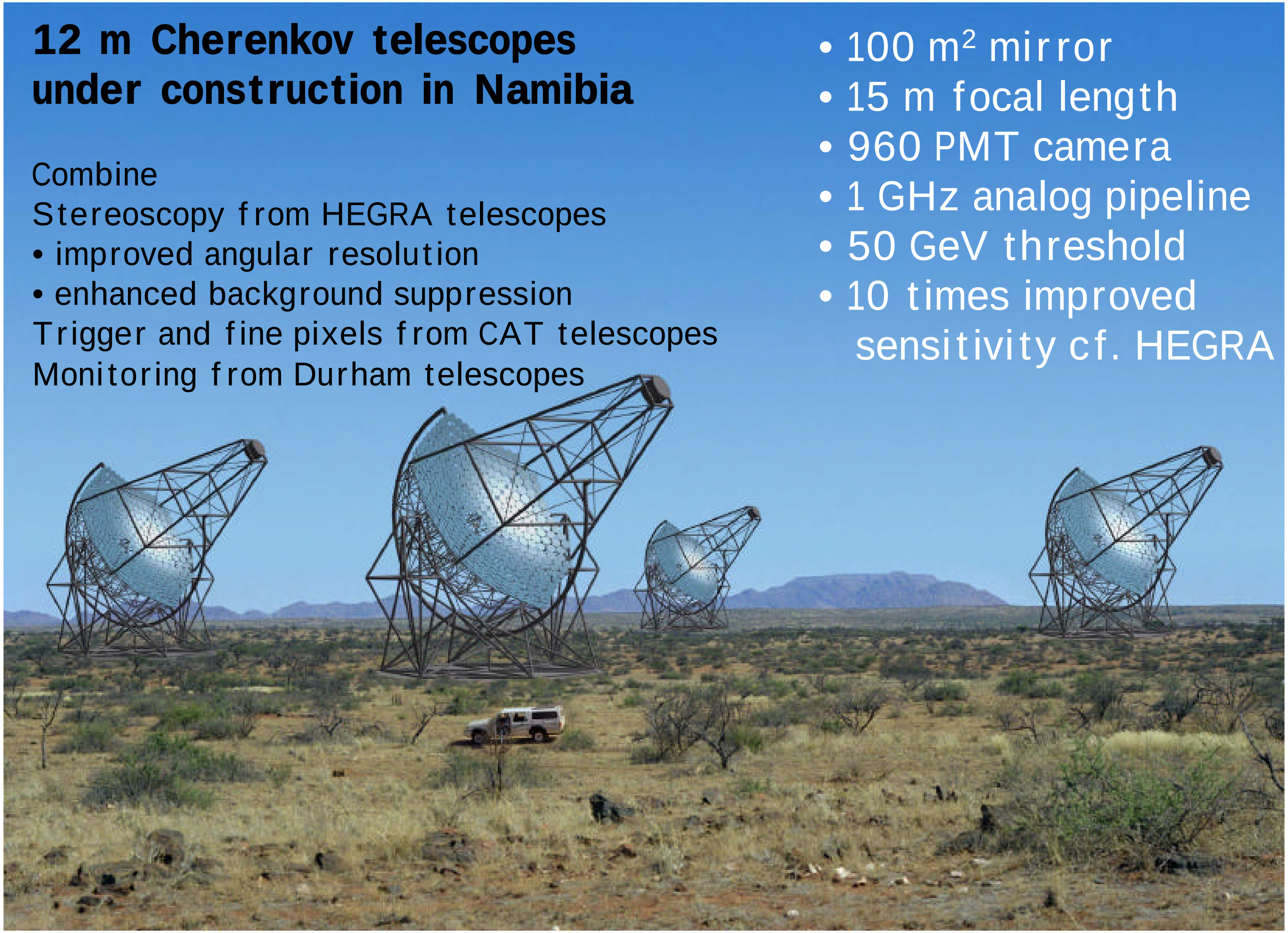
Combine

Stereoscopy from HEGRA telescopes
- improved angular resolution
- enhanced background suppression

Trigger and fine pixels from CAT telescopes

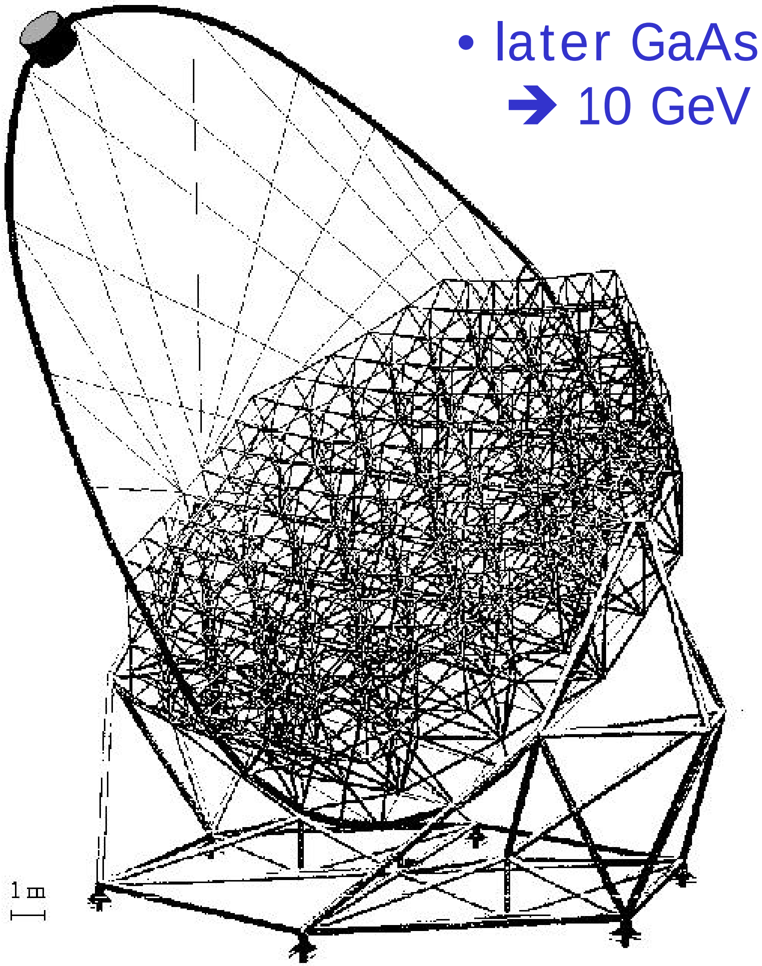
Monitoring from Durham telescopes

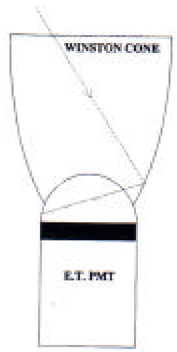
- 100 m^2 mirror
- 15 m focal length
- 960 PMT camera
- 1 GHz analog pipeline
- 50 GeV threshold
- 10 times improved sensitivity cf. HEGRA



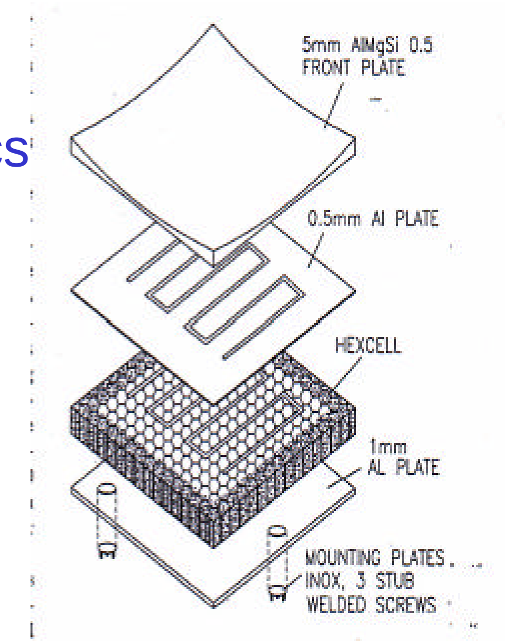
Source hunting with MAGIC

- 17 m dish, 220 m² active mirror
- low weight ➔ fast positioning
- high-speed optics and electronics
- initial PMT camera
- later GaAsP and APD detectors
  ➔ 10 GeV threshold



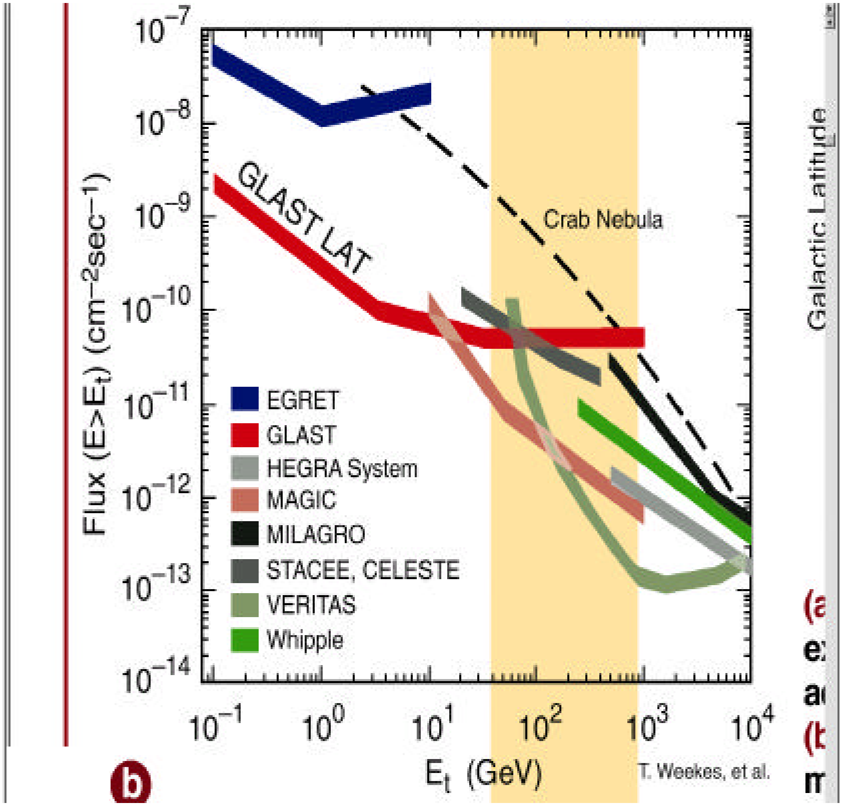


PMT with hemispherical window and optical signal transmission



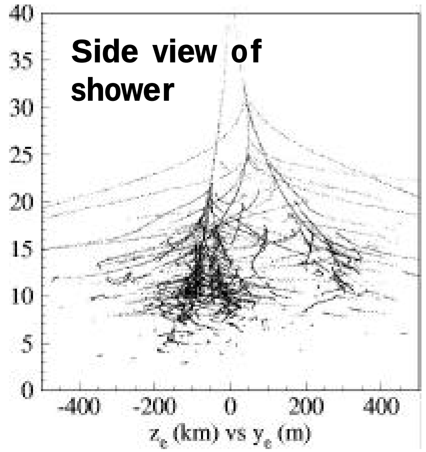
Aluminum mirrors

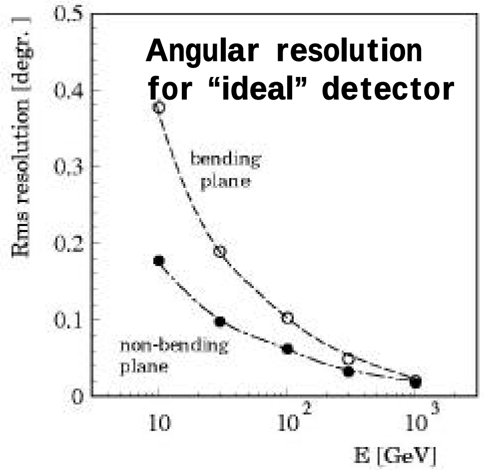
Sensitivity and limitations of the technique



Angular resolution,
cosmic-ray rejection limited by
- Shower fluctuations
- Earth magnetic field

Also, light yield depends on height!



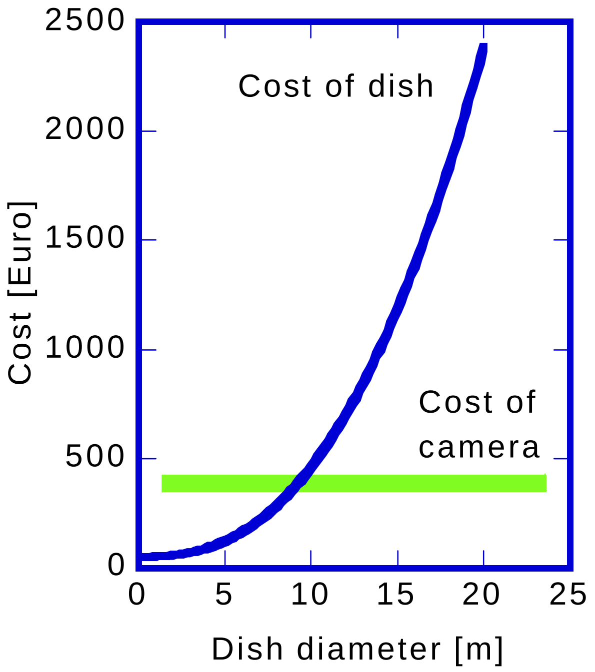


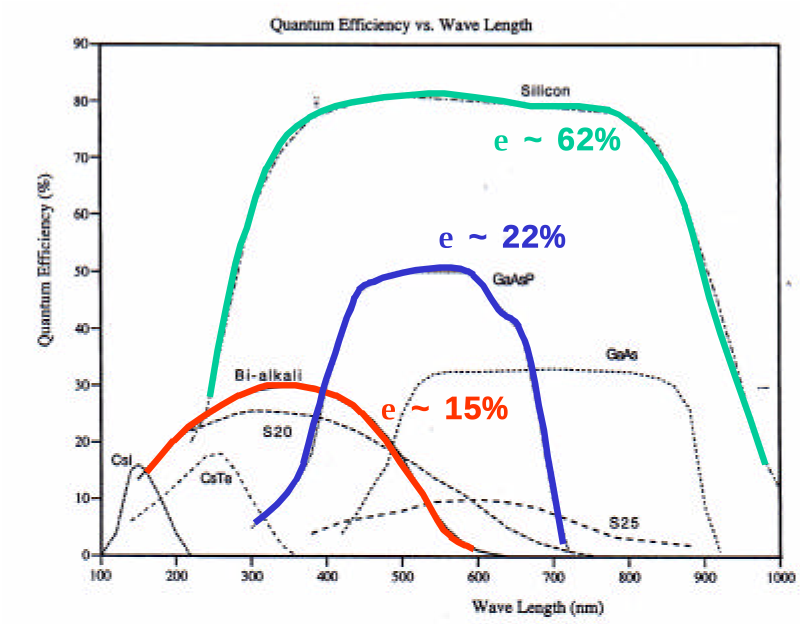
Hard to go beyond mCrab sensitivities with the imaging Cherenkov technique …

Irreducible background
- Cosmic-ray electrons

can only be discriminated on the basis of shower direction.

Better vision – novel photon detectors

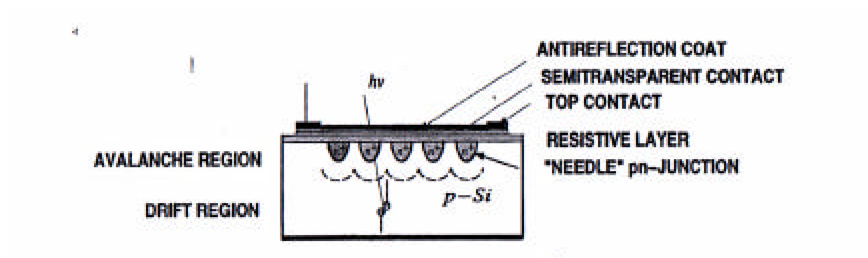




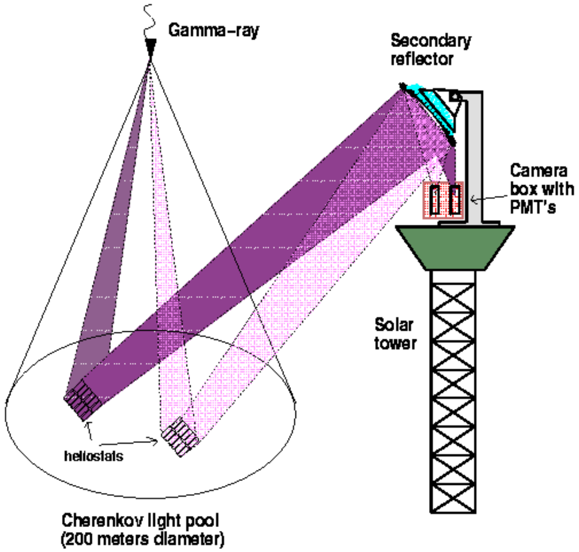
Better photon detectors
for Cherenkov telescopes
- allow large savings
- improve performance

need m² cathode area ...

- Hybrid PMTs
- GaAsP limited to few 100 mm²
- Si (APD) even smaller, QE below CCD



An alternative approach: non-imaging detectors



STACEE

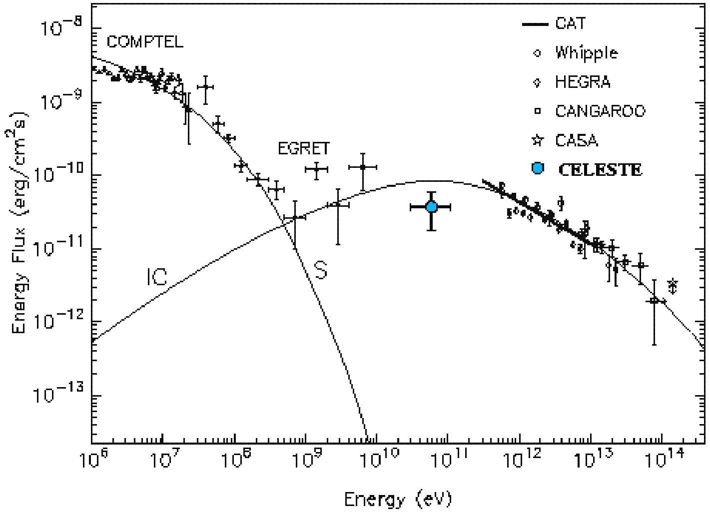
CELESTE secondary reflector and PMTs

Large mirror area and hence low energy threshold

Poor cosmic-ray rejection

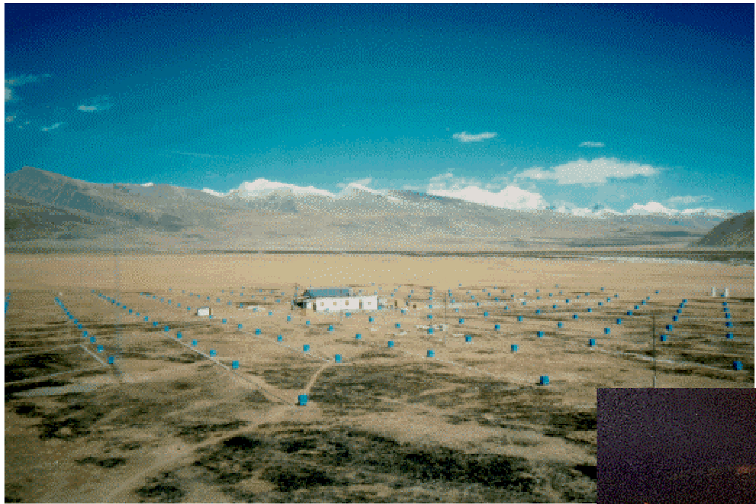
Significant learning curve

CELESTE sees Crab at 50 GeV

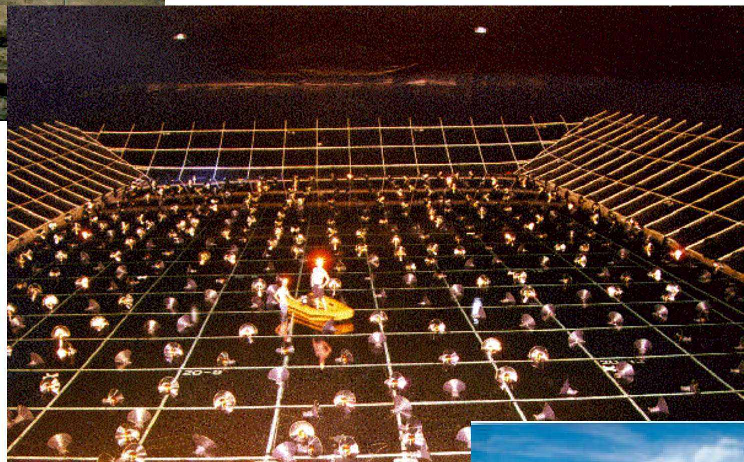


Competitive in the long run?

Tail catchers: particle detectors



Tibet air shower array (Scintillators)



Milagro, Los Alamos (Water Cherenkov)

High altitude and large area coverage

ARGO,Tibet (RPC array)

Avantages

- large solid angle
- 100% duty cyle

Disadvantages

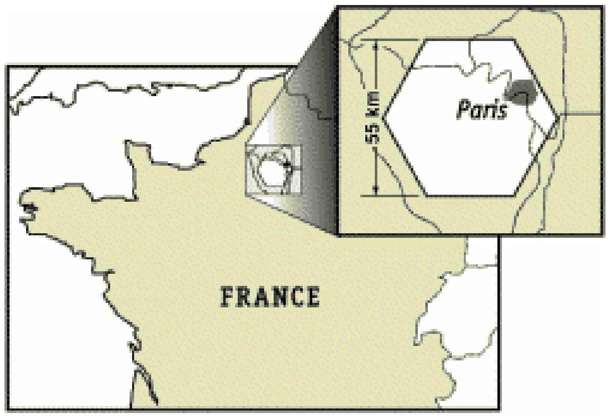
- TeV+ threshold
- marginal (Crab-level) sensitivity

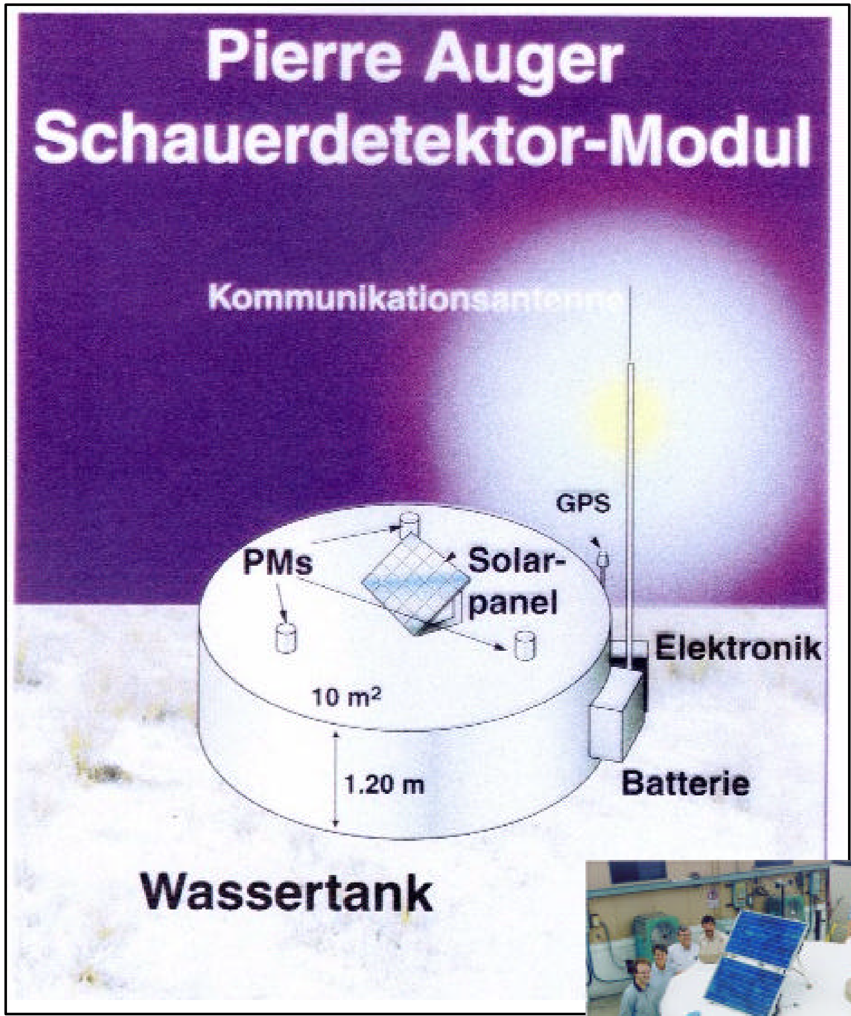
Complementary to Cherenkov telescopes

The ultimate experience: AUGER

Air shower detector

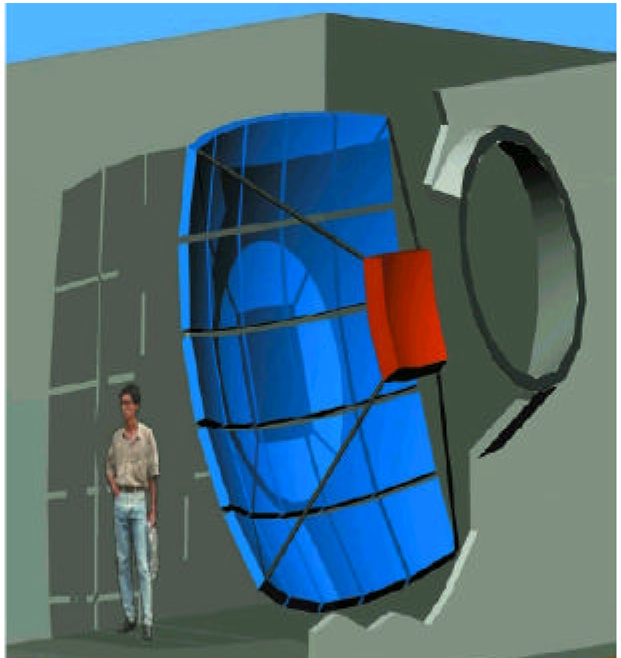
- 3000 km^2 area
- two detector technologies
    - particle detectors
    - fluorescence telescopes
- ~ 20000 events > 10^{19} eV
- ~ 100 events > 10^{20} eV

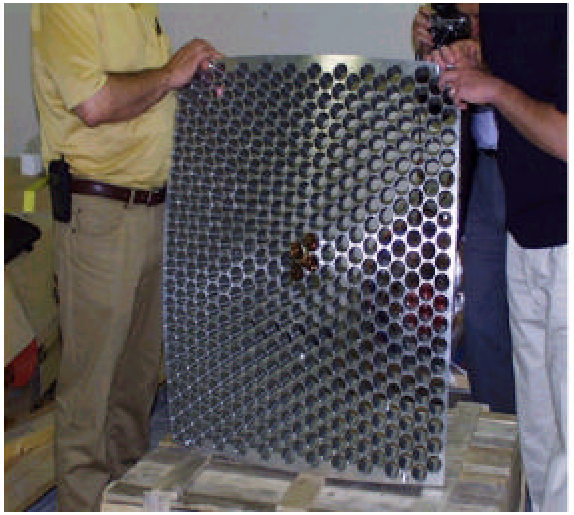


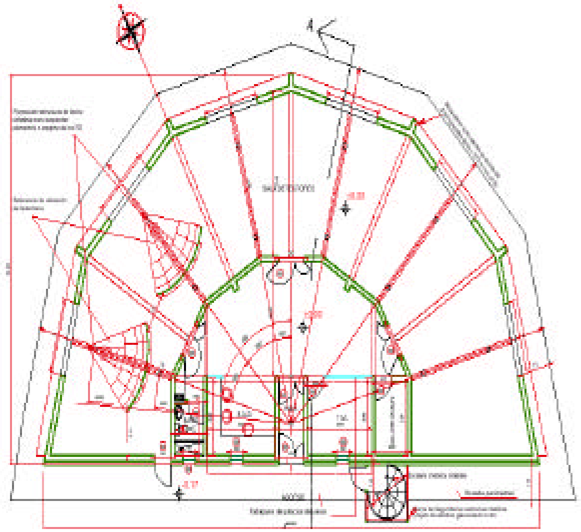


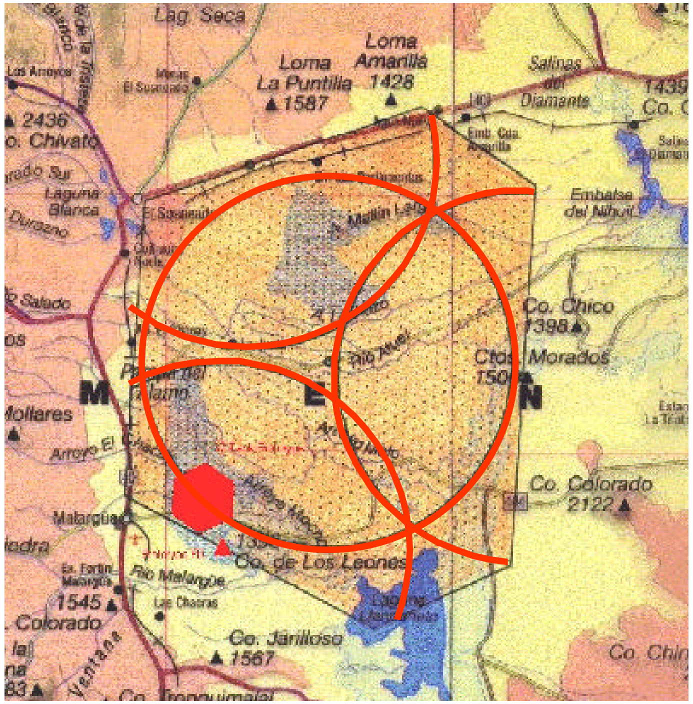
1600 detectors
1.5 km spacing

AUGER fluorescence detectors

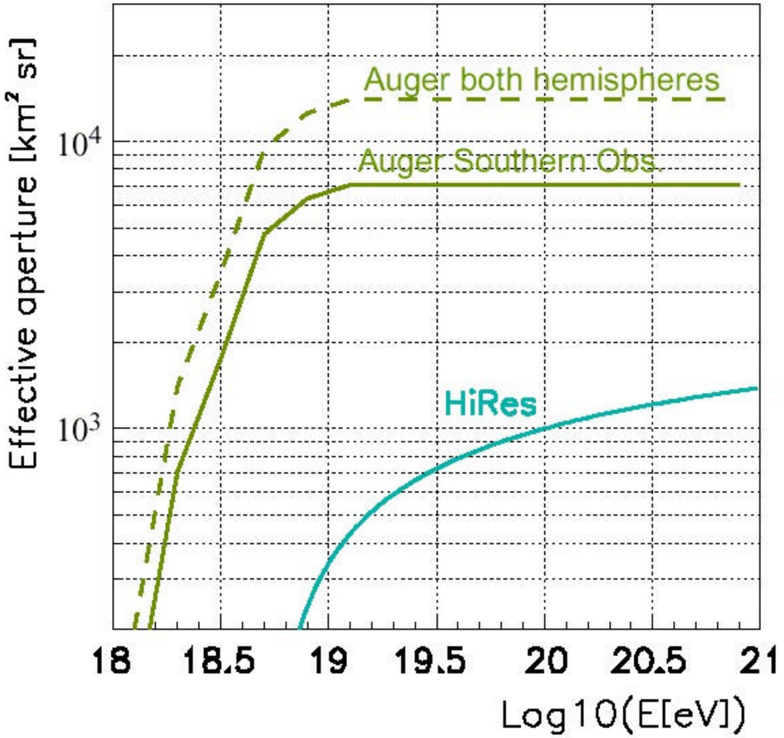






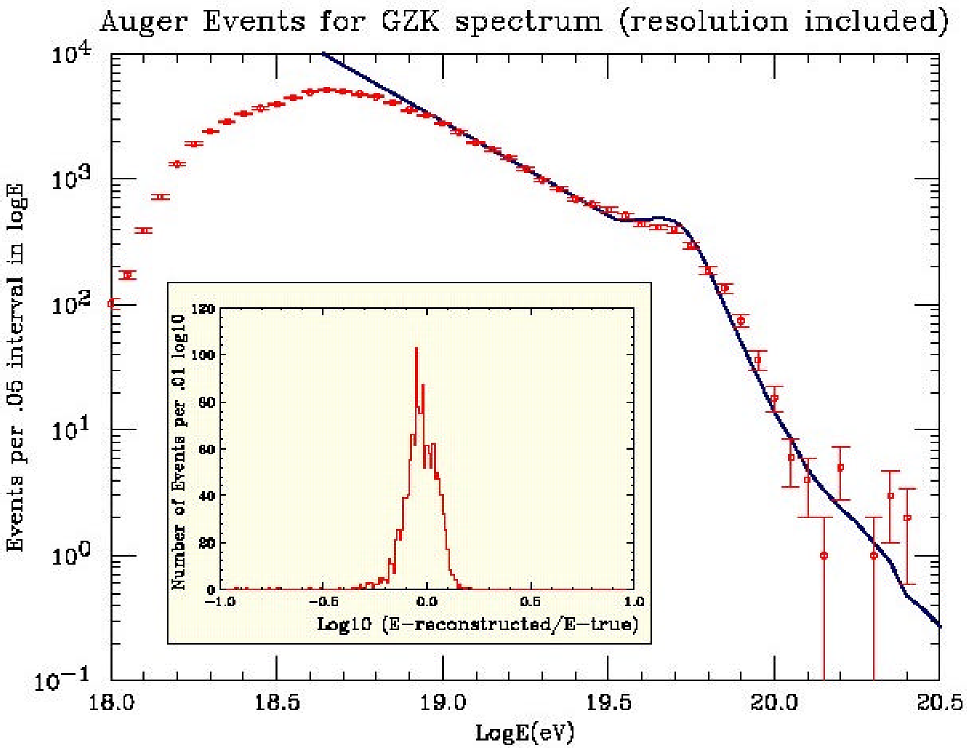


AUGER performance

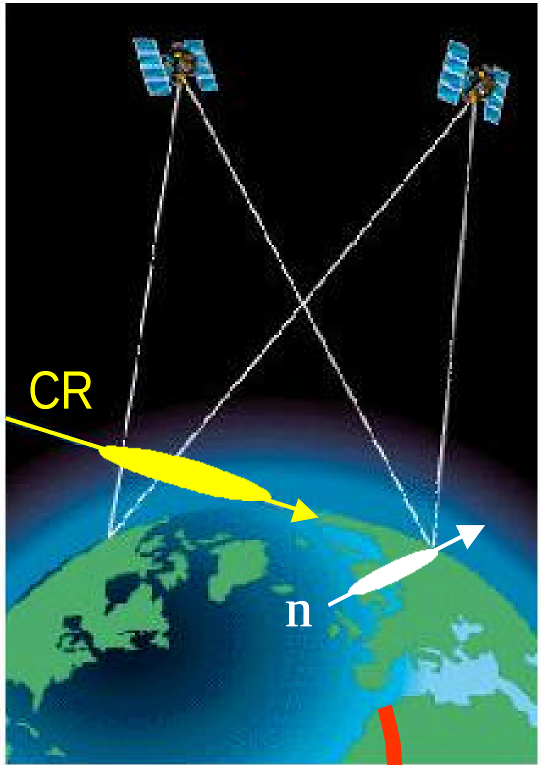


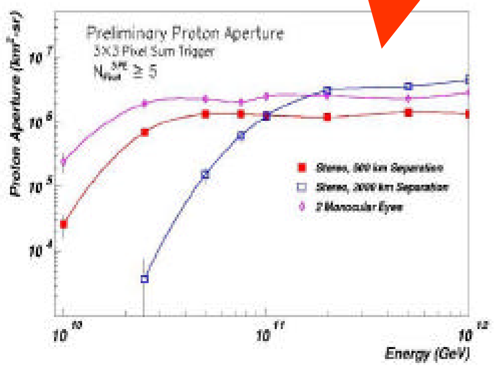
Detection area

Simulated spectrum

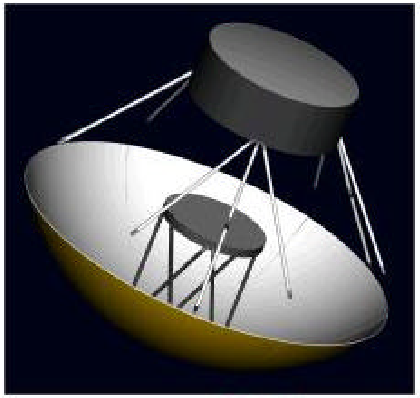


The view from above: OWL

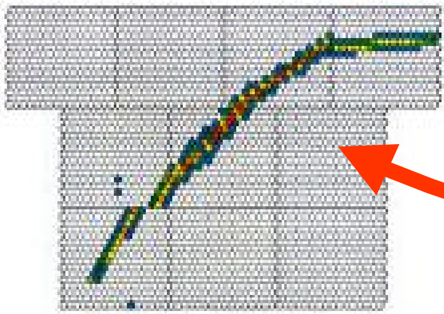




Threshold: 10^{19}-10^{20} eV
Eff. area: few 10^6 km^{2}sr

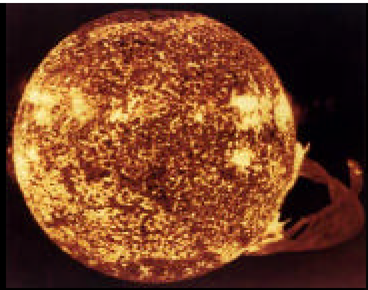


> 50^o field of view



10^6 pixel focal plane
flat panel PMTs ?

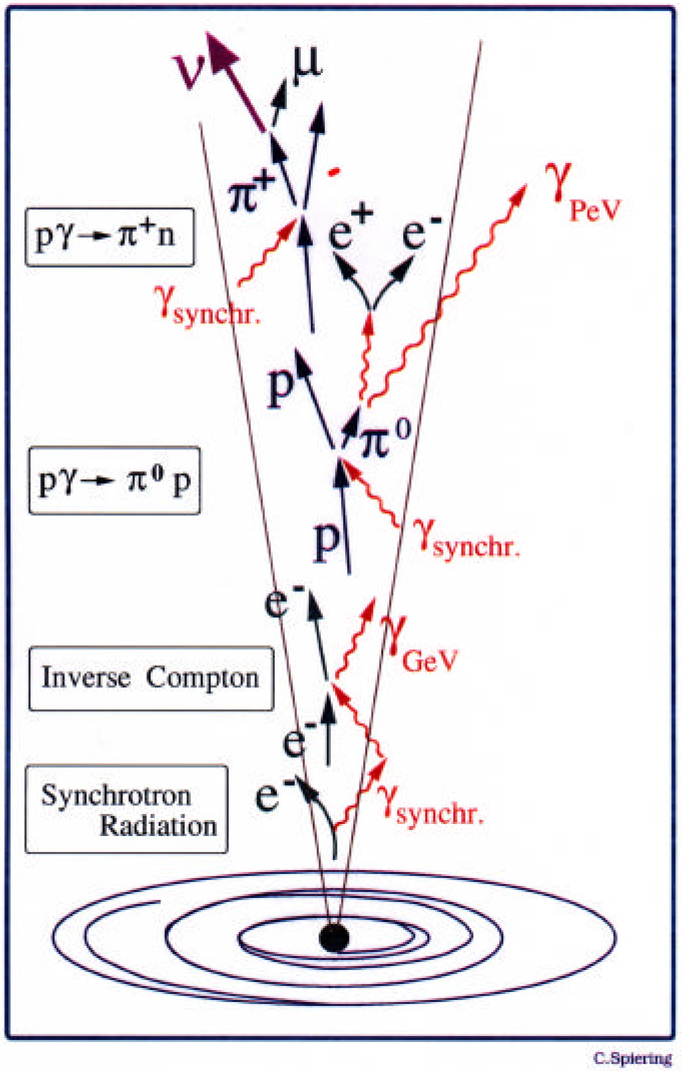

University of California, Los Angeles
UCLA Faculty Center
November 16-18, 2000
UCLA
RADHEP
2000
FIRST INTERNATIONAL WORKSHOP ON
RADIO DETECTION OF HIGH-ENERGY PARTICLES



Neutrinos
(MeV: sun, SN
GeV: atmosphere
PeV: CR accerators)

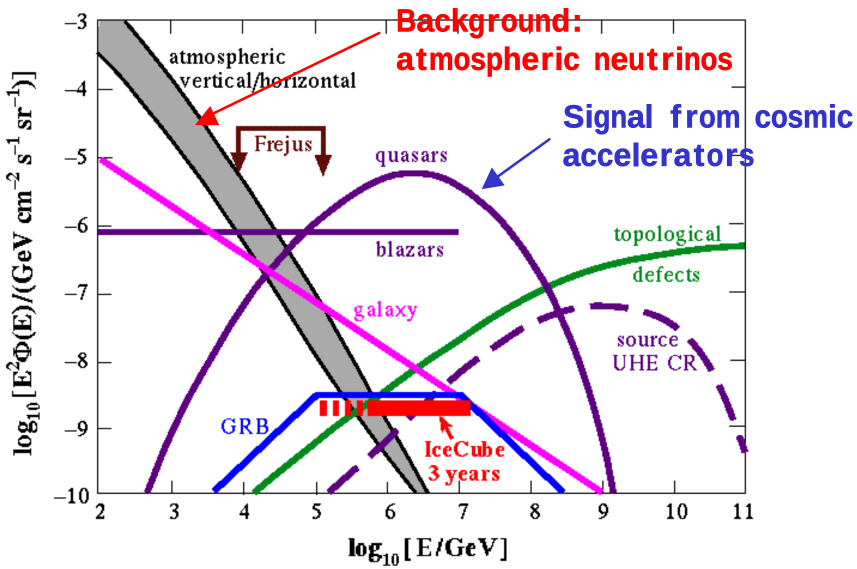
High-Energy Neutrino Astrophysics

Particle Generation in AGN Jets



Proton accelerators generate roughly equal numbers of gamma rays and neutrinos !

- Neutrinos are not absorbed in sources; they escape even from strong sources
- Neutrinos do not interact during propagation

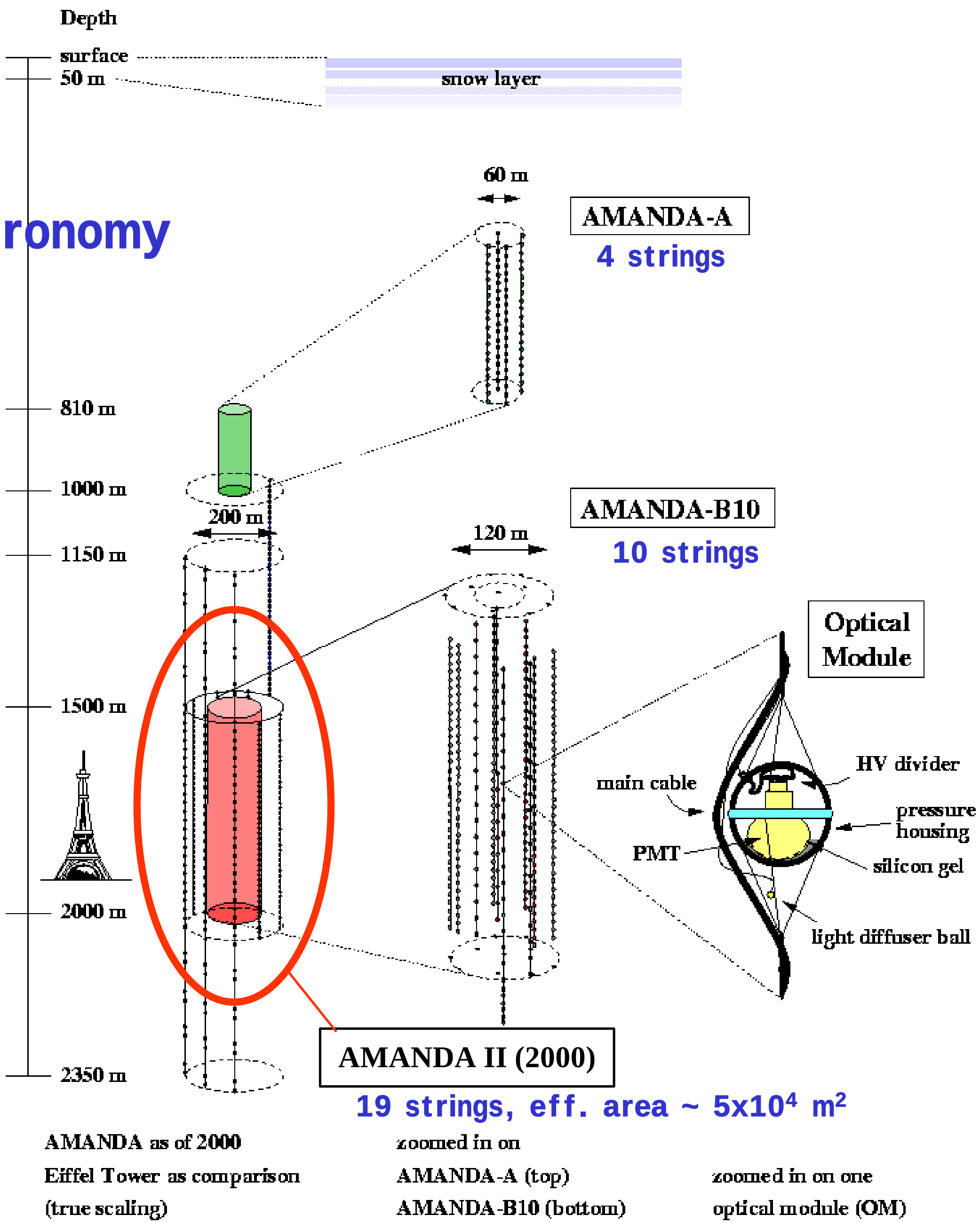


Scientific American

Extreme Engineering Issue

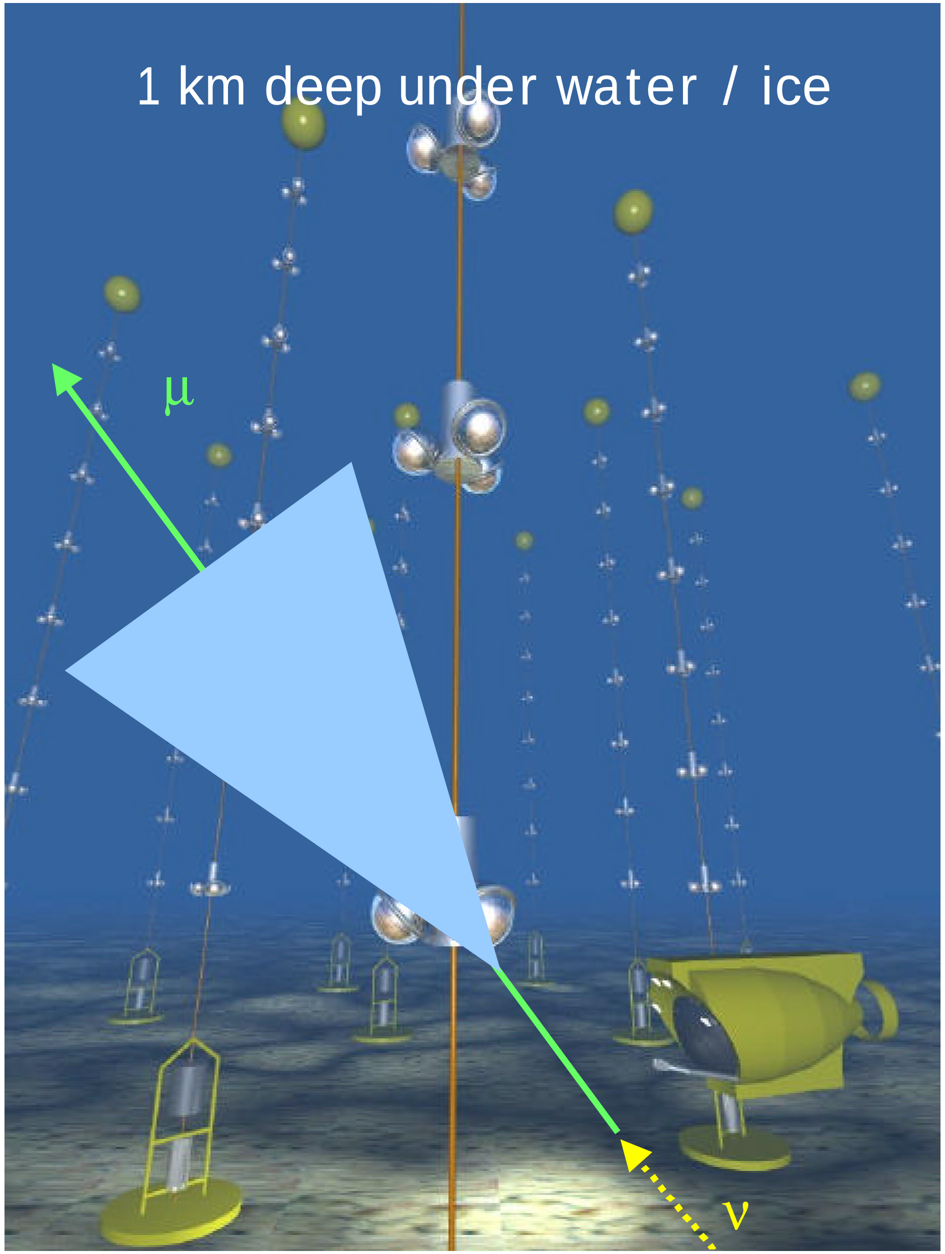
Seven wonders of modern astronomy

- The sharpest
- The biggest
- The farthest flung
- The most extensive
- The swiftest
- The deadliest
- **The weirdest: AMANDA at the south pole**



Detection: Cherenkov light in water / ice

ICE CUBE,
ANTARES:
1000000000 m^3
~ 5000 PMTs
Threshold ~ 1 TeV



Key difference:

Ice / AMANDA II:
- ~ 100 m absorption length,
- ~ 20 m scattering length
- ➔ diffusive component
- ➔ angular resolution 1.2^o

Water / ANTARES, NESTOR
- ~ 60 m absorption length,
- ~ 200 m scattering length
- ➔ angular resolution 0.2^o

Instrument R&D

- Optical module design
- Deployment schemes
- PMTs
- Signal transmission
- Digital modules

ANTARES Demonstrator

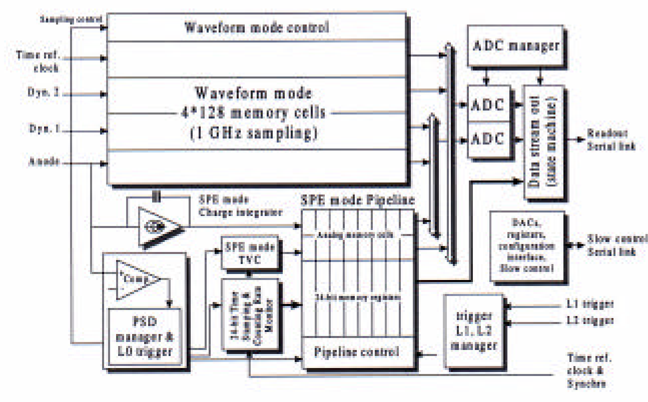
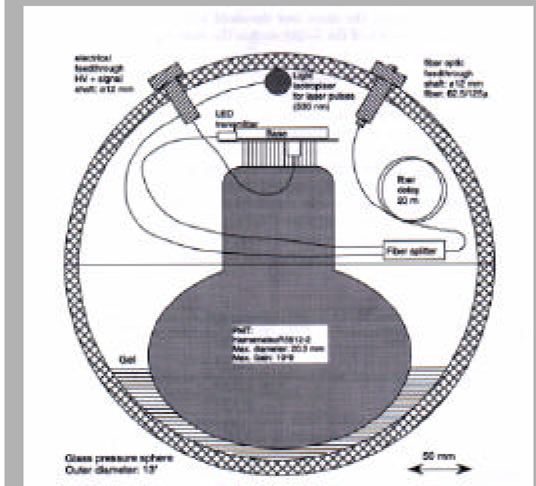
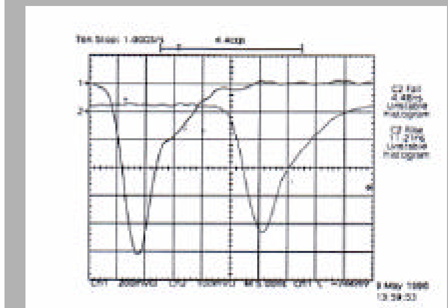


Fig. 8. ARS1 bloc diagram

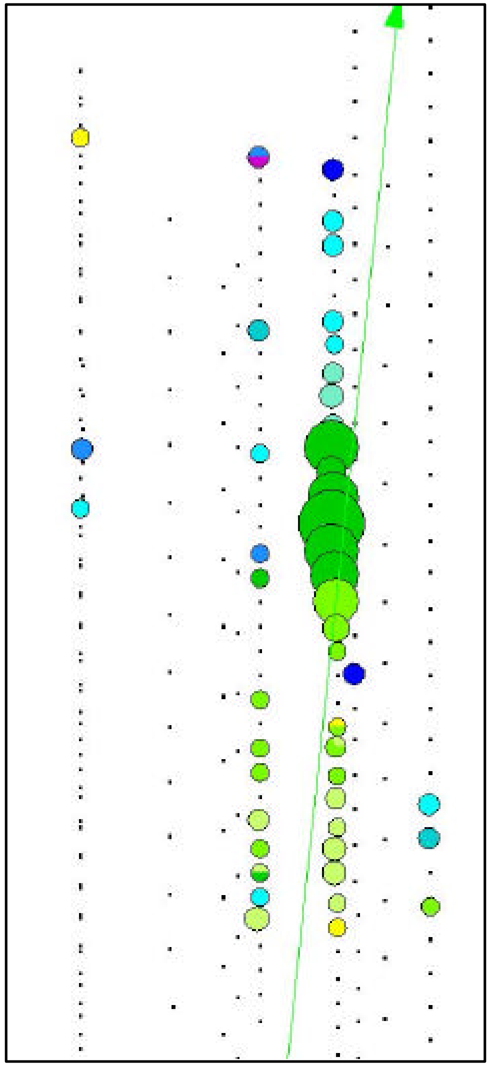
ARS 1 GHz analog ring sampler ASIC with digital signal procession (ANTARES)

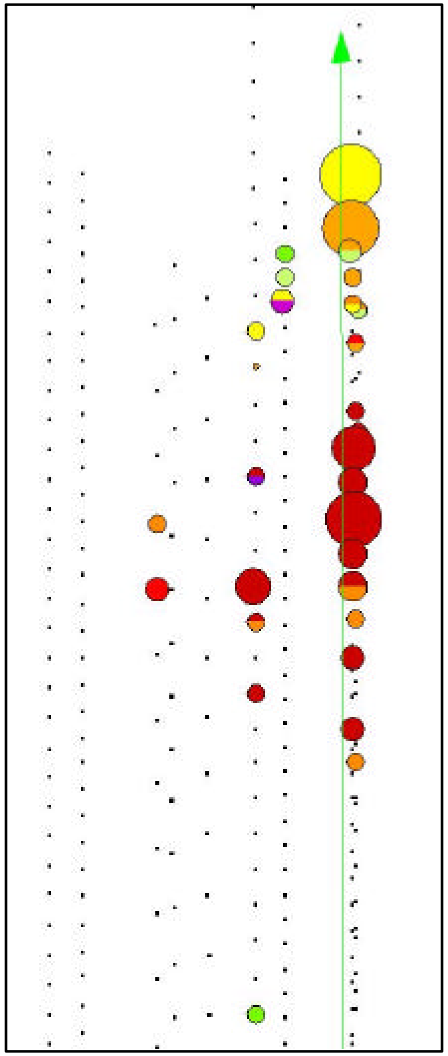


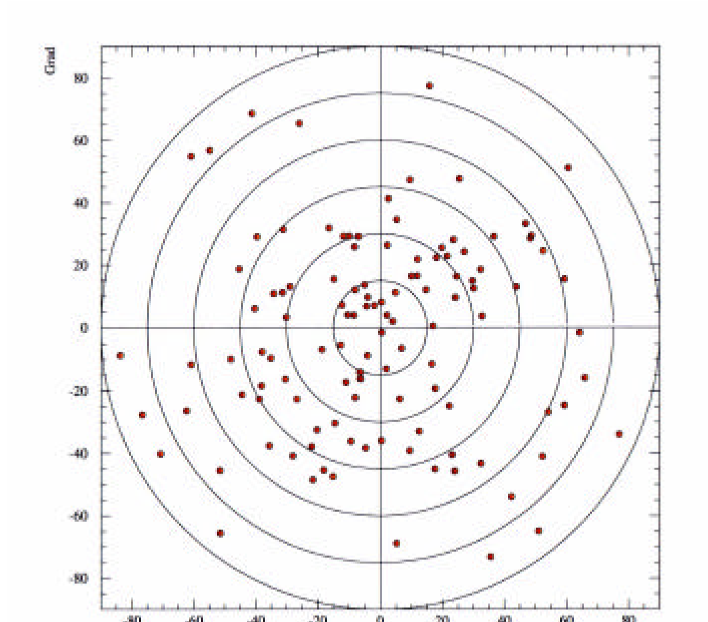


Module with optical signal transmission (AMANDA)

AMANDA at the South Pole

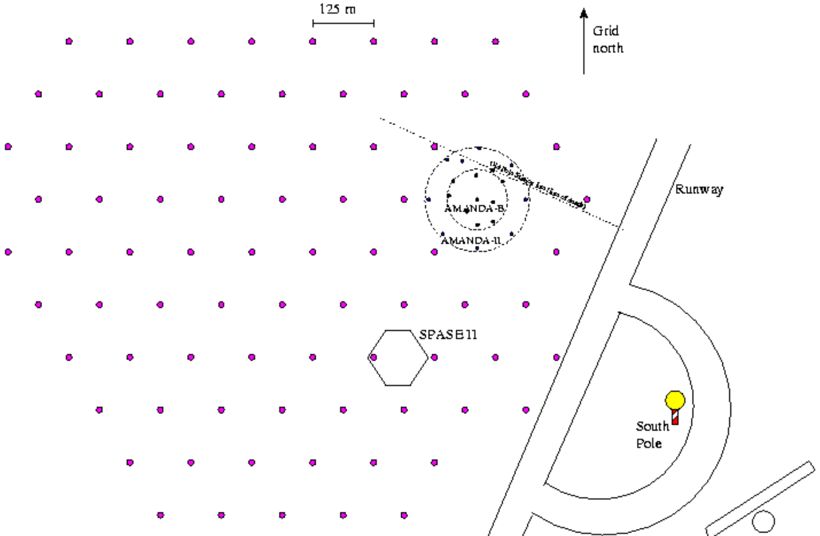


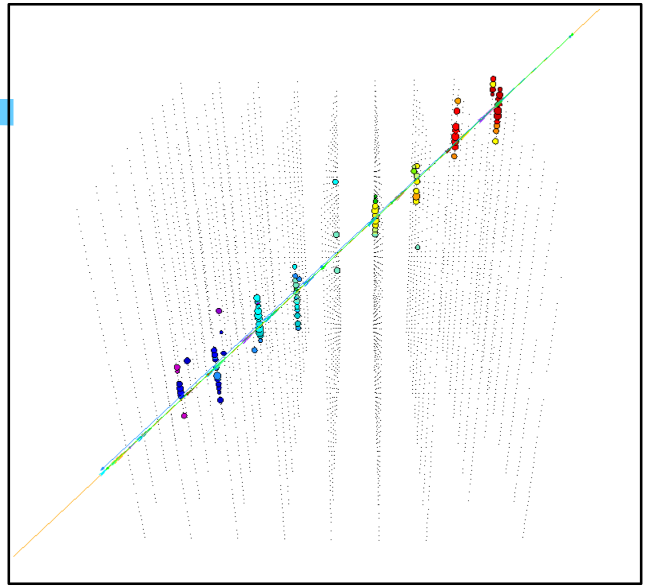


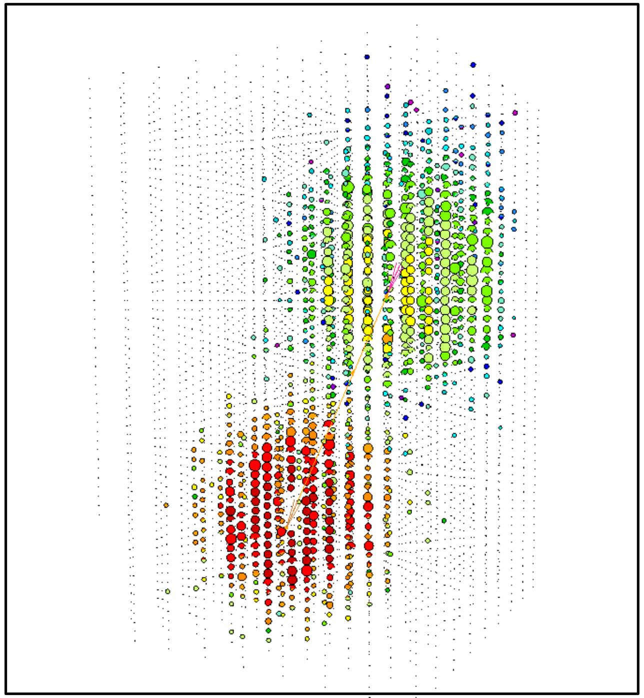


ν-Sky (AMANDA '97)

ICECUBE



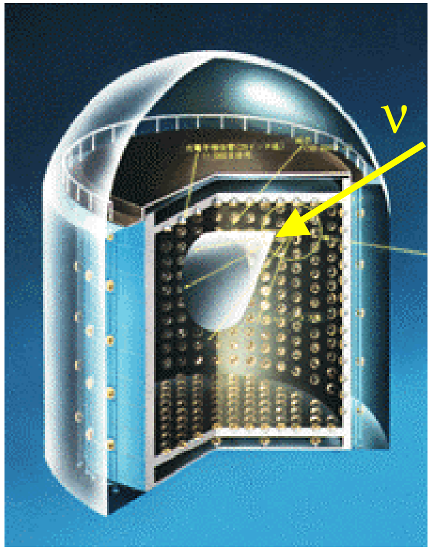




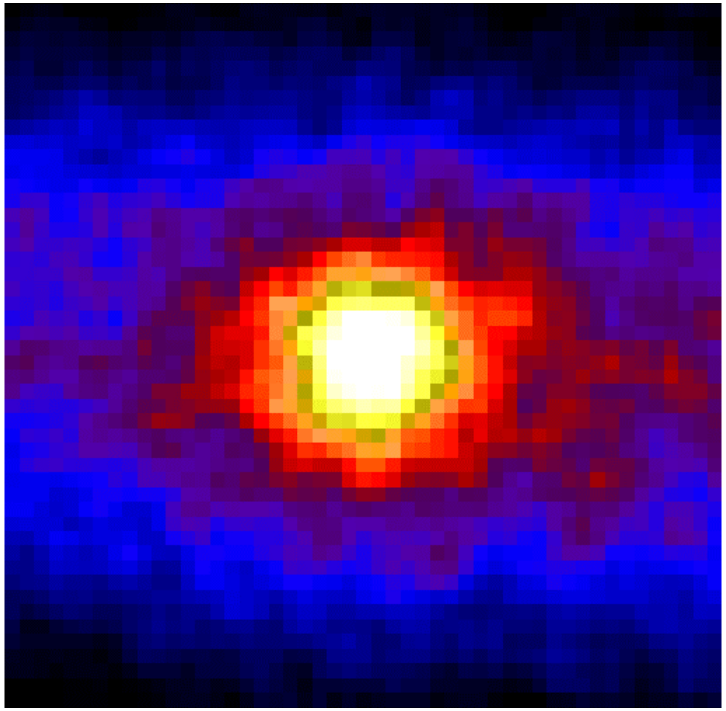
80 “Strings” of 60 PMTs
in 1400 – 2300 m depth

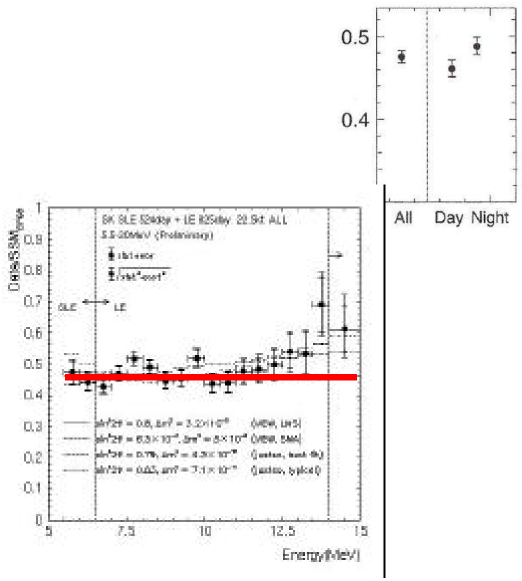
Physics issues (**ICECUBE, ANTARES, NESTOR**):
- neutrinos from CR accelerators
- neutrinos from DM annihilation
- atmospheric neutrinos, oscillations
- magnetic monopoles
- galactic supernovae
- ...

Solar neutrinos



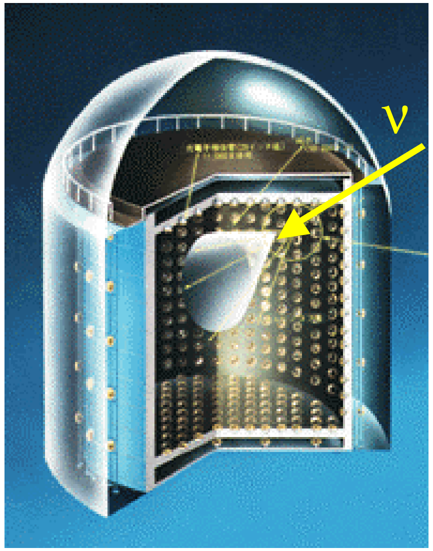
Super-Kamiokande:
the neutrino image of the sun



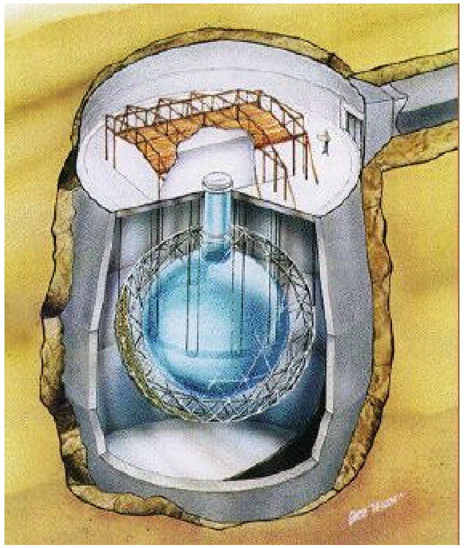


Detectors for solar (MeV) neutrinos

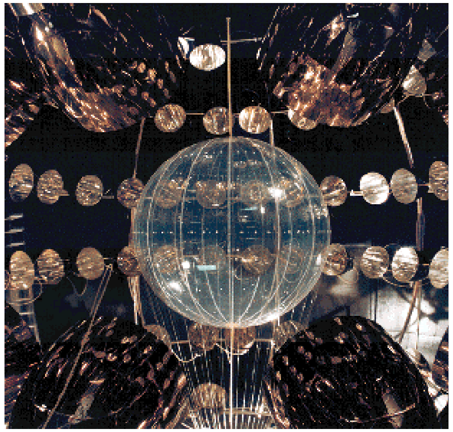
SuperKamiokande
Water Cherenkov



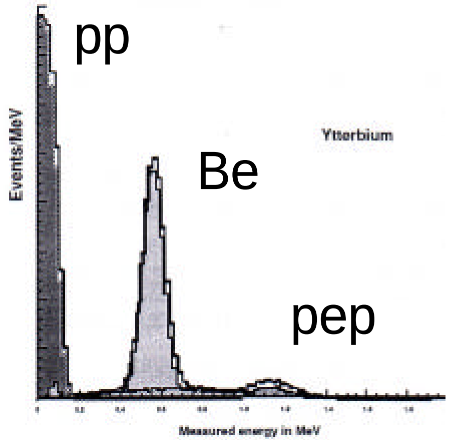
SNO: Heavy-Water Cherenkov

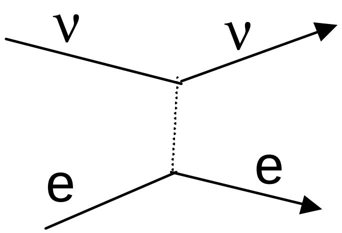


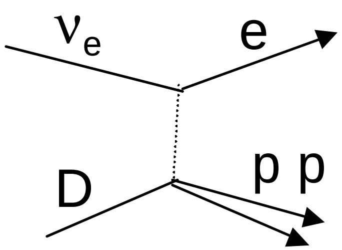
BOREXINO, KAMLAND(2):
Liquid Scintillator

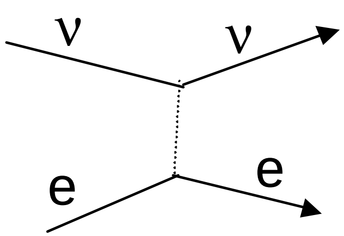


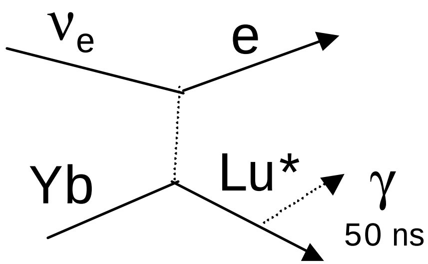
LENS:
Liquid Scintillator with "Tag"







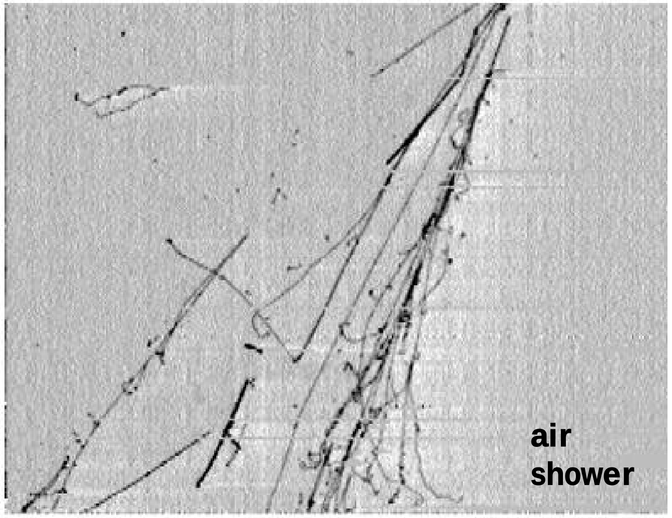




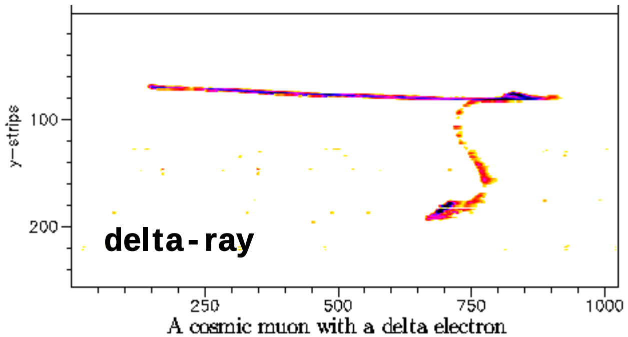
n-flavor	**no (NC)**	**yes (CC)**	**no (NC)**	**yes (CC)**
n-energy res.	**poor**	**good**	**poor**	**good**
threshold	**4-5 MeV**	**4-5 MeV**	**1 MeV**	**0.3 MeV**

Alternative techniques

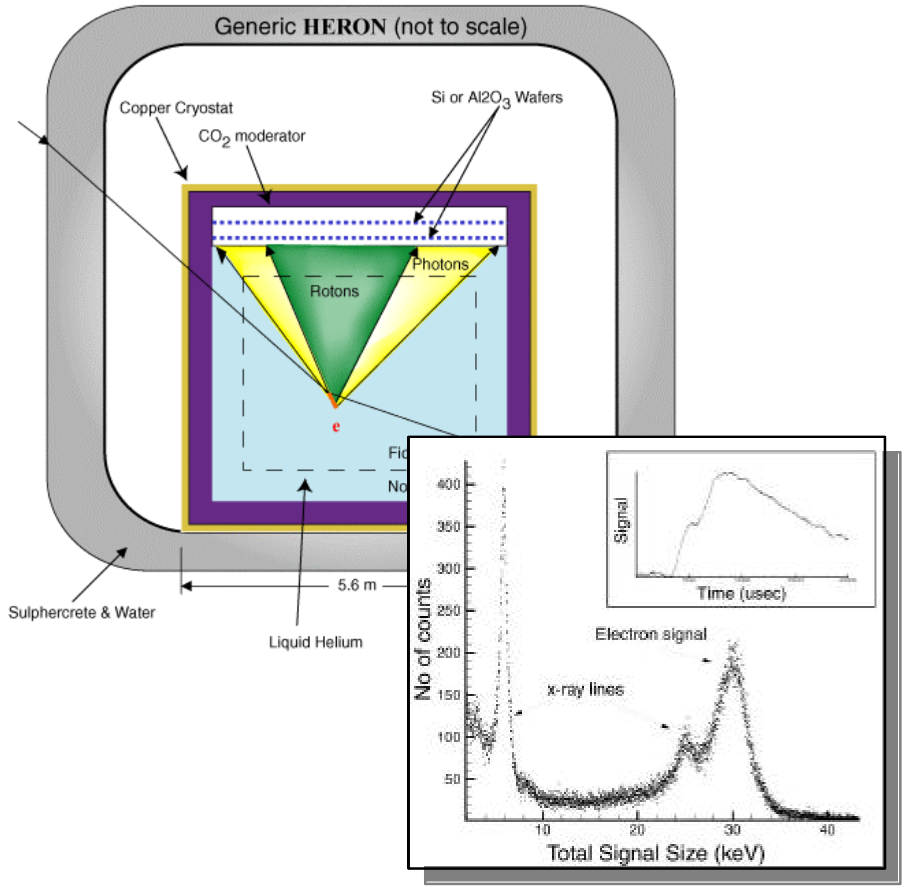
ICARUS: liquid argon DC

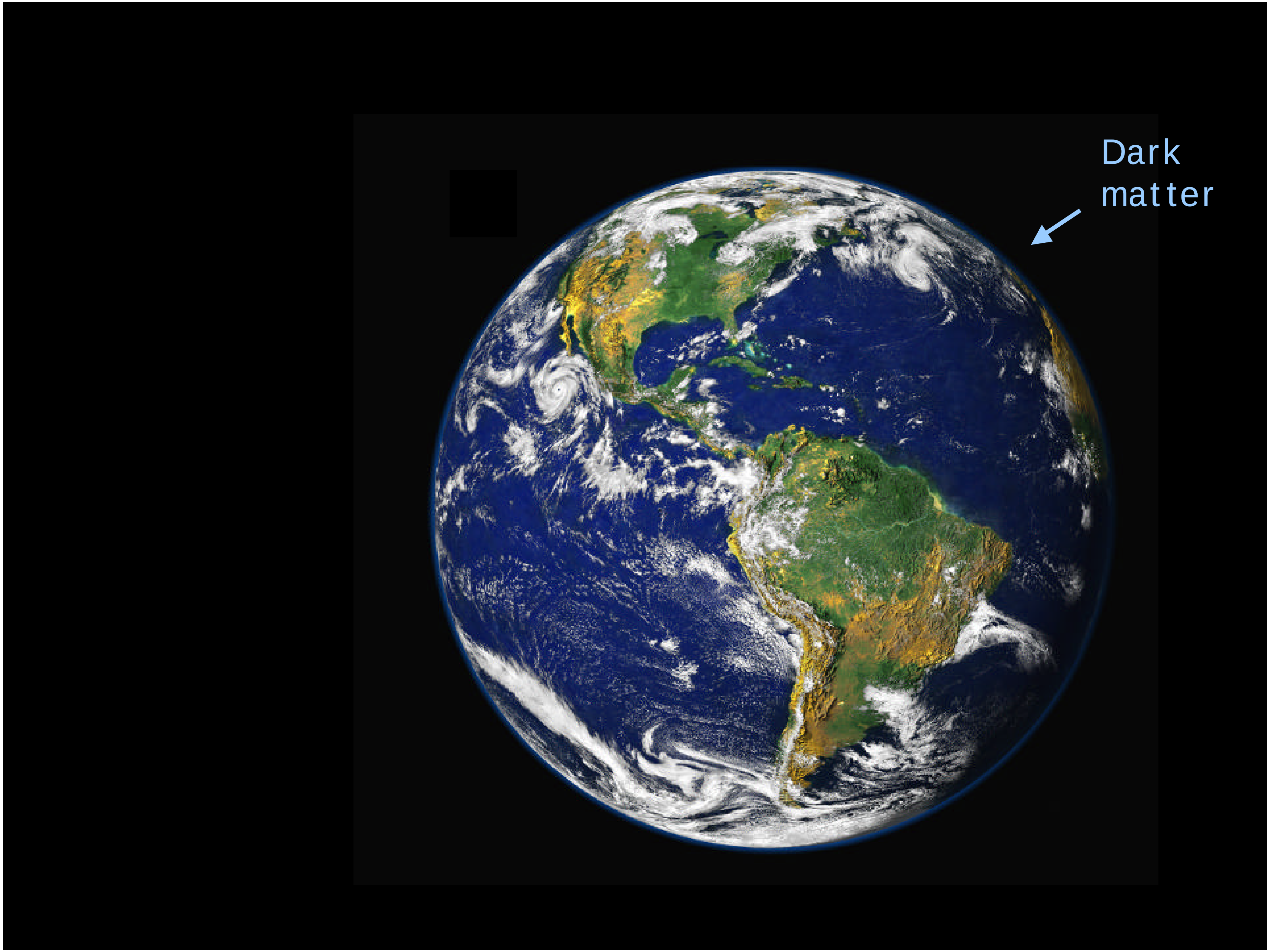


HELLAZ: TPC

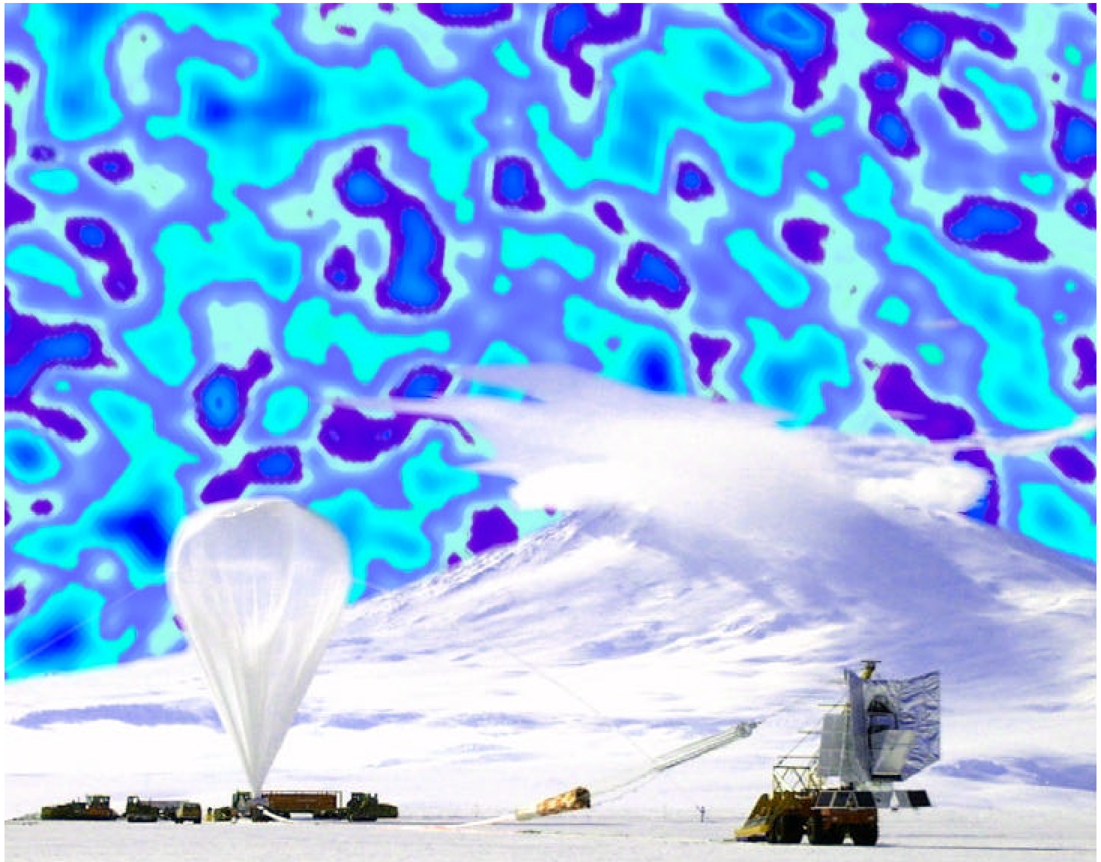


HERON: superfluid He; evaporation by photons/rotons and scintillation




Dark
matter

The dark side of the universe



CMB (Boomerang, Maxima)
High-z Supernovae, BBN

$\Omega \sim 1.0$
$\Omega_M \sim 0.2\text{-}0.3$
$\Omega_B \sim 0.03 – 0.05$

➔ most matter is dark, nonbaryonic

Particle physics candidates, e.g. WIMPs, accumulate in the halo of galaxies (local density 0.3 GeV/cm^3)

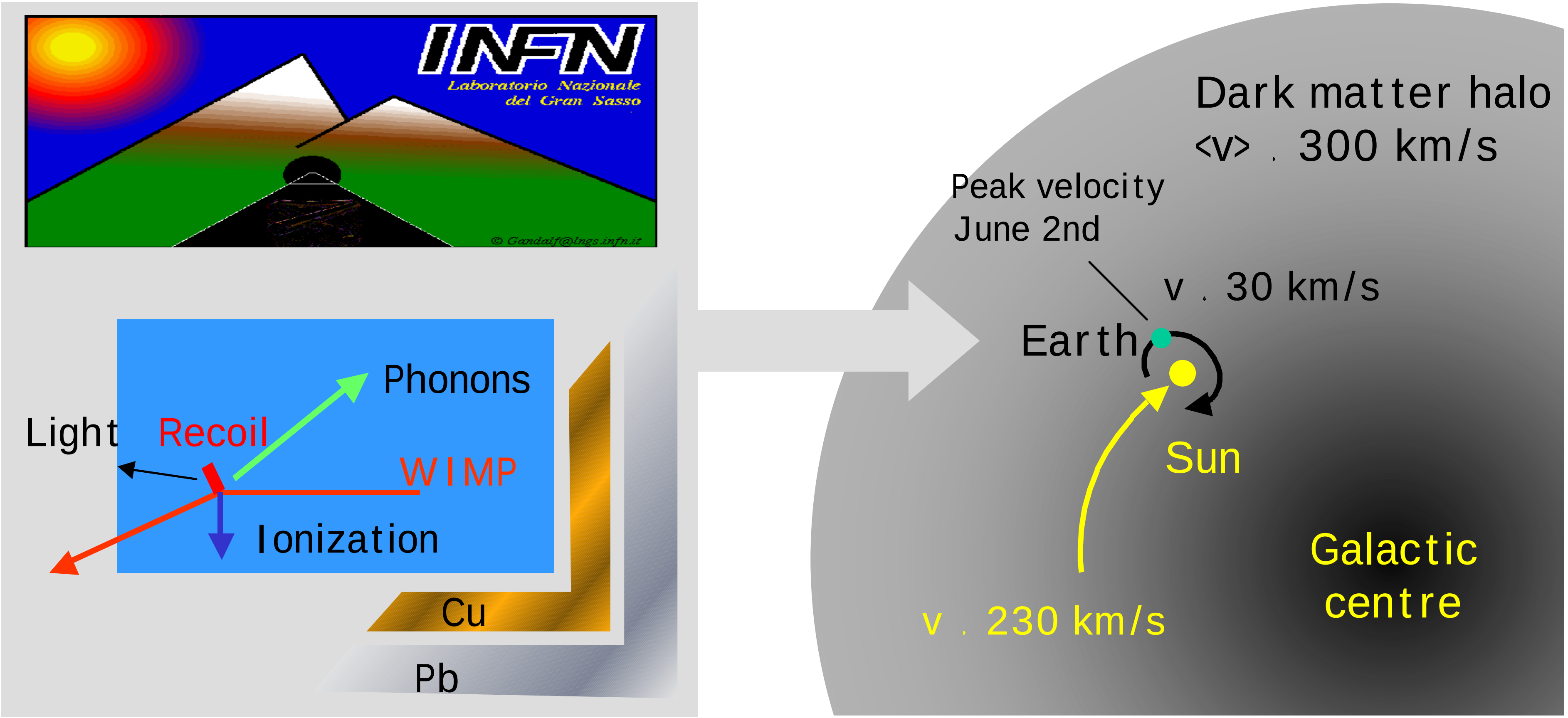
Searching for WIMPs

Principle: elastic scattering on nuclei

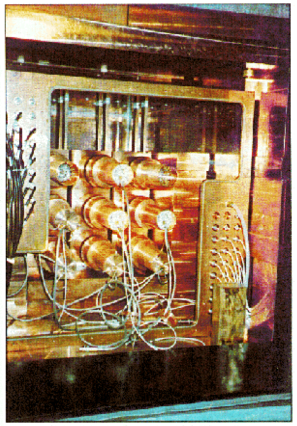
$$E_R = m_W v^2 \frac{m_W M}{(m_W + M)^2}(1 - \cos q)$$

Typ. recoil: a few 100 eV / GeV WIMP mass
Typ. rate: a few events / kg / day

WIMP Signature:
7% annual modulation



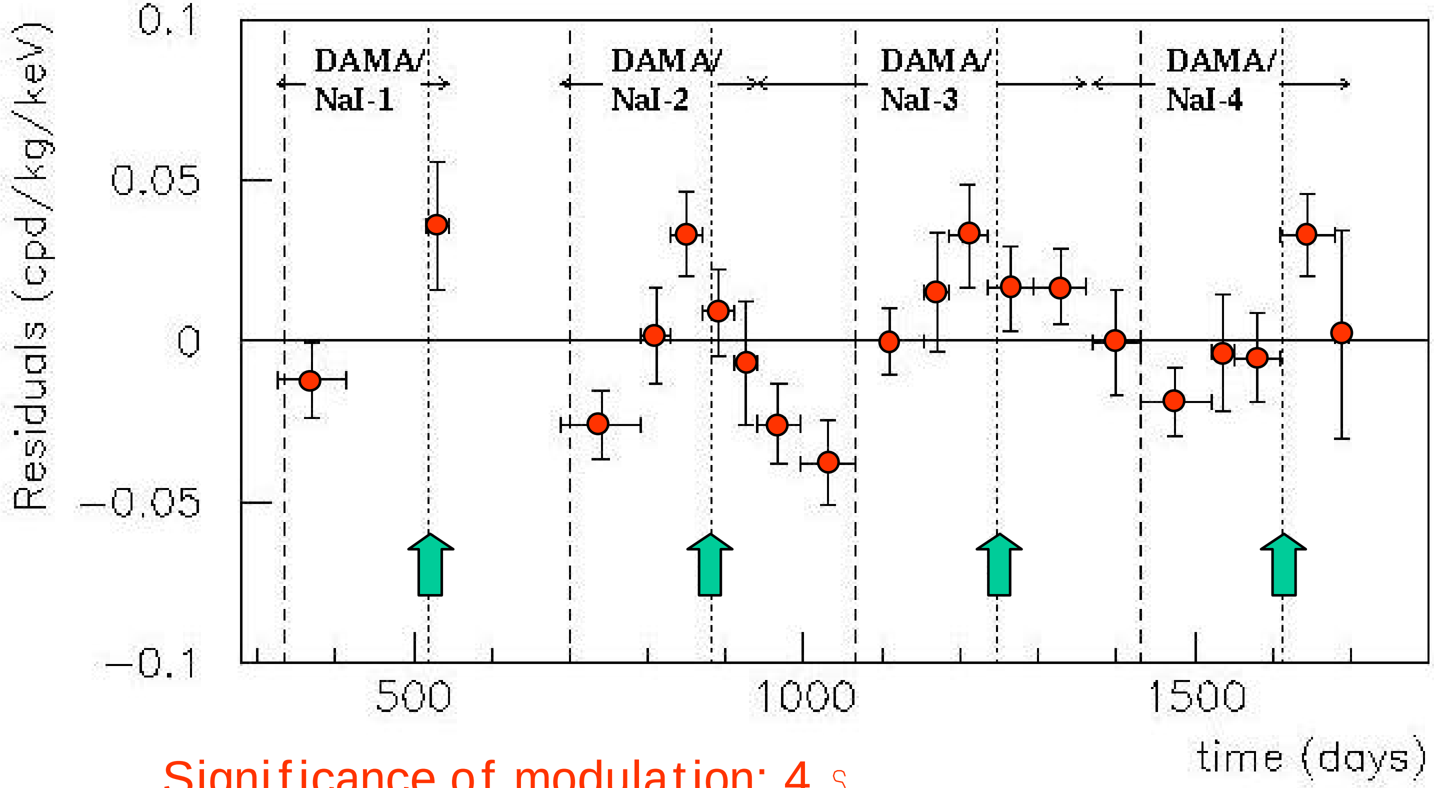
The classical approach: DAMA



9 NaI dectors, total ~100 kg
Threshold ca. 1-2 keV (equiv. Energy)
Background ca. 1.5-2 /kg keV Day

Similar: UKDMC, ...

Deviation from average rate, 2 – 6 keV

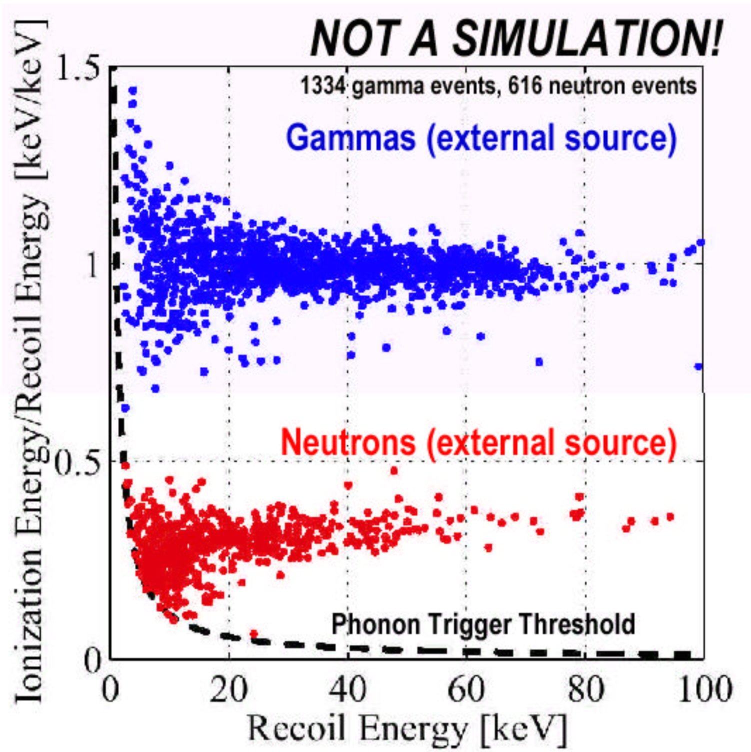


+3%
0
-3%

Significance of modulation: 4 σ
near threshold rate saturated by dark matter!

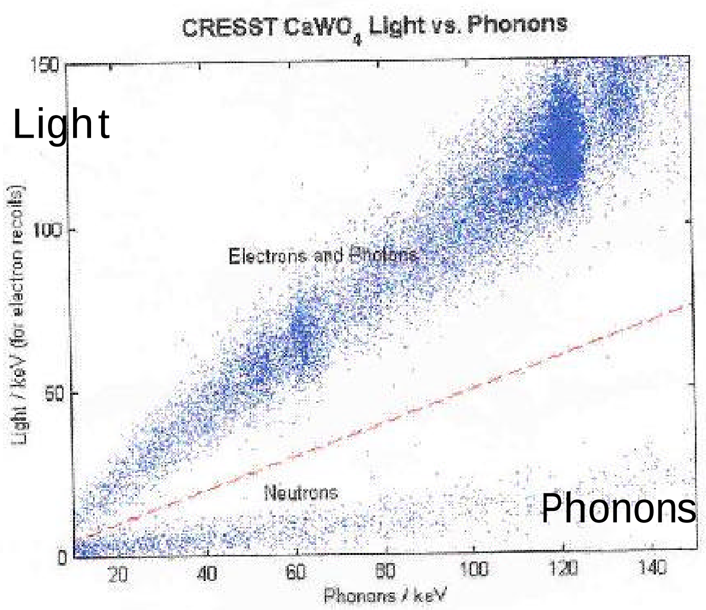
Mind over matter: cryogenic detectors

$\frac{\text{Ionisation}}{\text{Phonons}}$



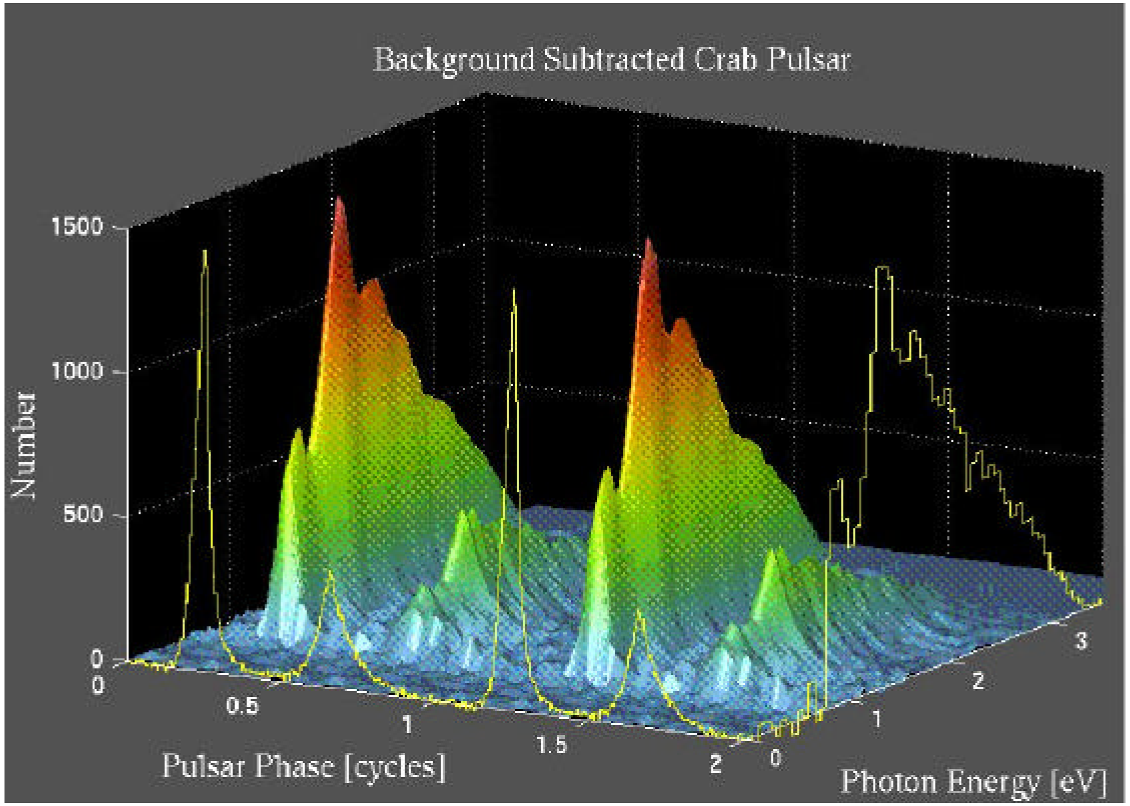
Phononen

CDMS (Si, Ge)
Thermometer: superconducting film near transition (20 mk); Ionisation
(and Edelweiss, ...)



CRESST ($CaWO_4$)
Thermometer: superconducting film (15 mK)
Detection of light using absorber with thermometer

Reach of cryogenic detectors



Romani et al.

Spectroscopy of single photons from the Crab pulsar

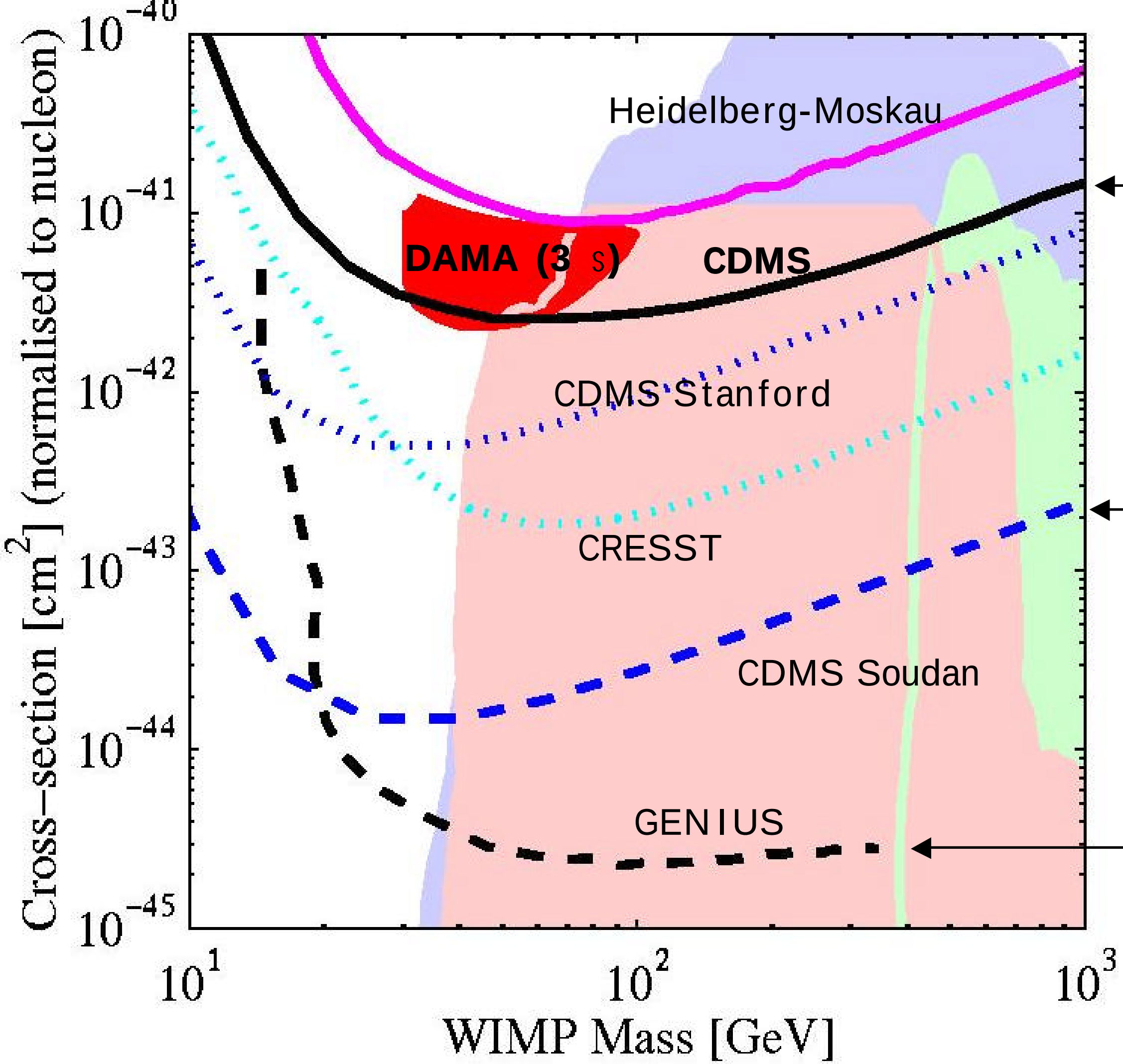
Transition edge sensor coupled to W detector (18μ x 18μ x 40 nm)

$\Delta E < 0.15$ eV

Challenges: Size
Resolution
Speed (usually limited to kHz)

CDMS vs. DAMA ... and the future

R. Gaitskill, V. Mandic
http://cdms.berkeley.edu/limitplots/



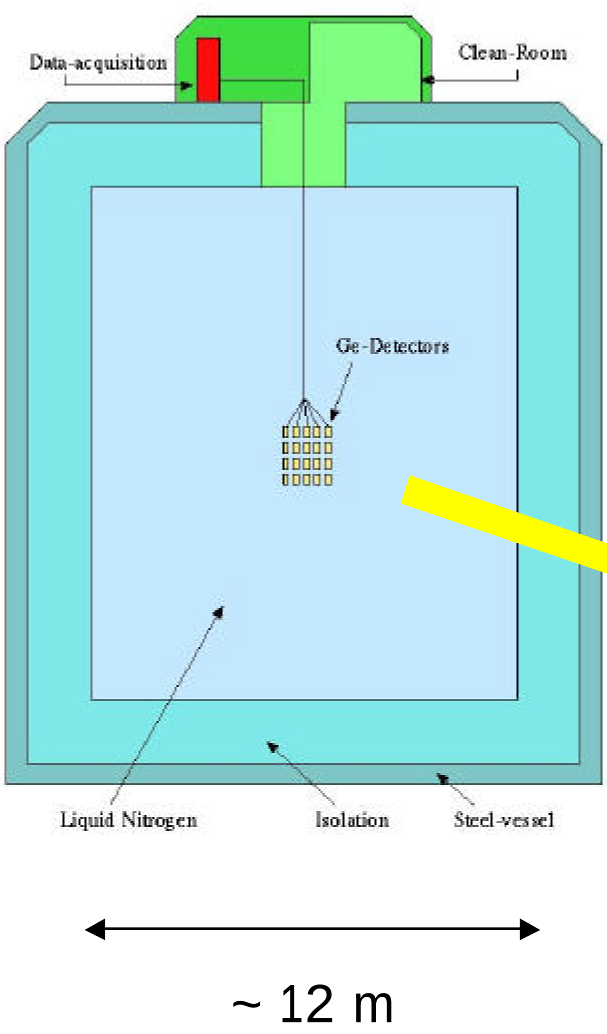
DAMA
58000 kg-days
3800 m water equiv.

CDMS:
11 kg-days
16 m water equiv.

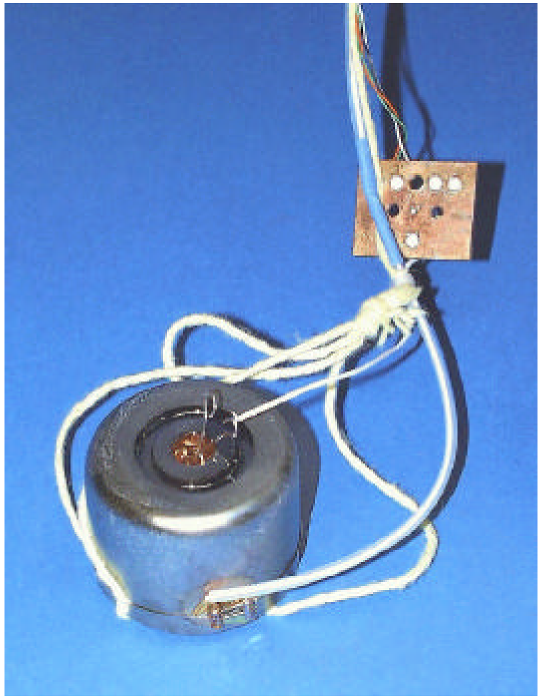
CDMS Soudan

GENIUS

GENIUS: the simpler the better ?



Germanium detectors (100 kg) supended in ultra-pure liquid nitrogen

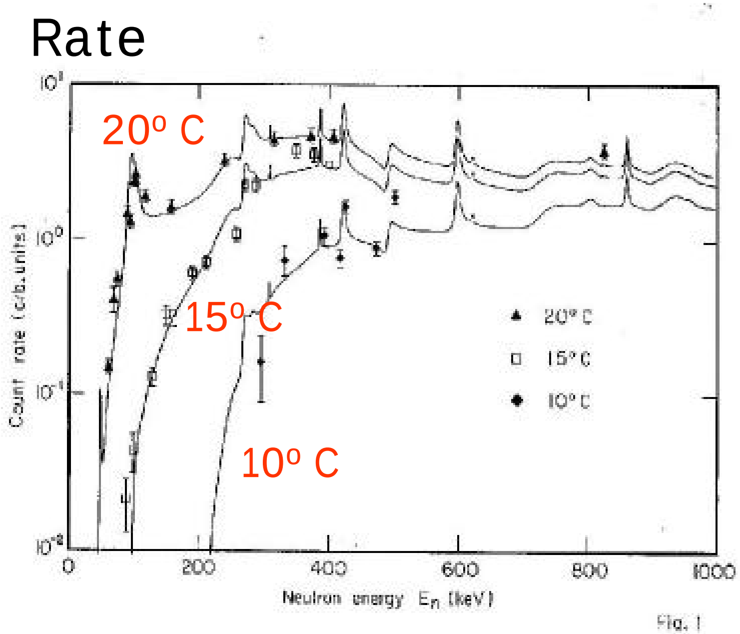


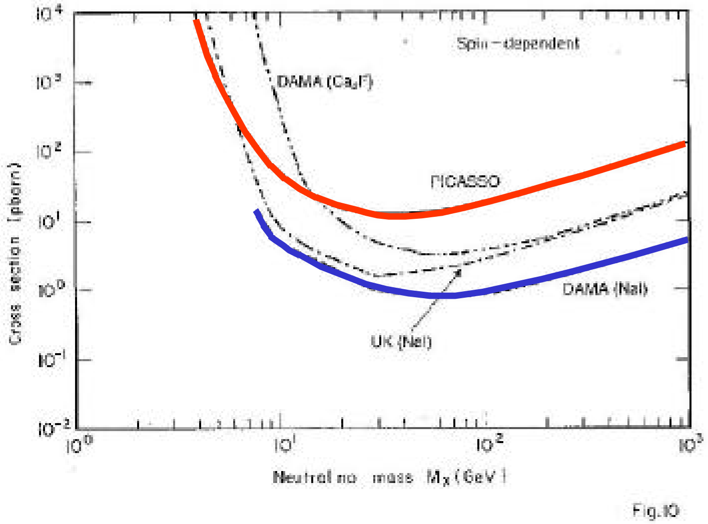
Test facility under construction at LNGS

Bubble chamber revival: Picasso

The Picasso detectors: superheated droplets in a polymerized gel. Detection via noise (piezo transducer)

dE/dx threshold adjusted by detector temperature





First results – not yet competitive, but in the right ballpark

Astroparticle Physics

- a fascinating application of particle physics instrumentation to new questions
- numerous interesting and challenging developments, both in physics and instrumentation

- impossible to do the field justice in 45 min. !