Position Sensitive Detectors for Astroparticle Physics

Timothy J Sumner

Imperial College London

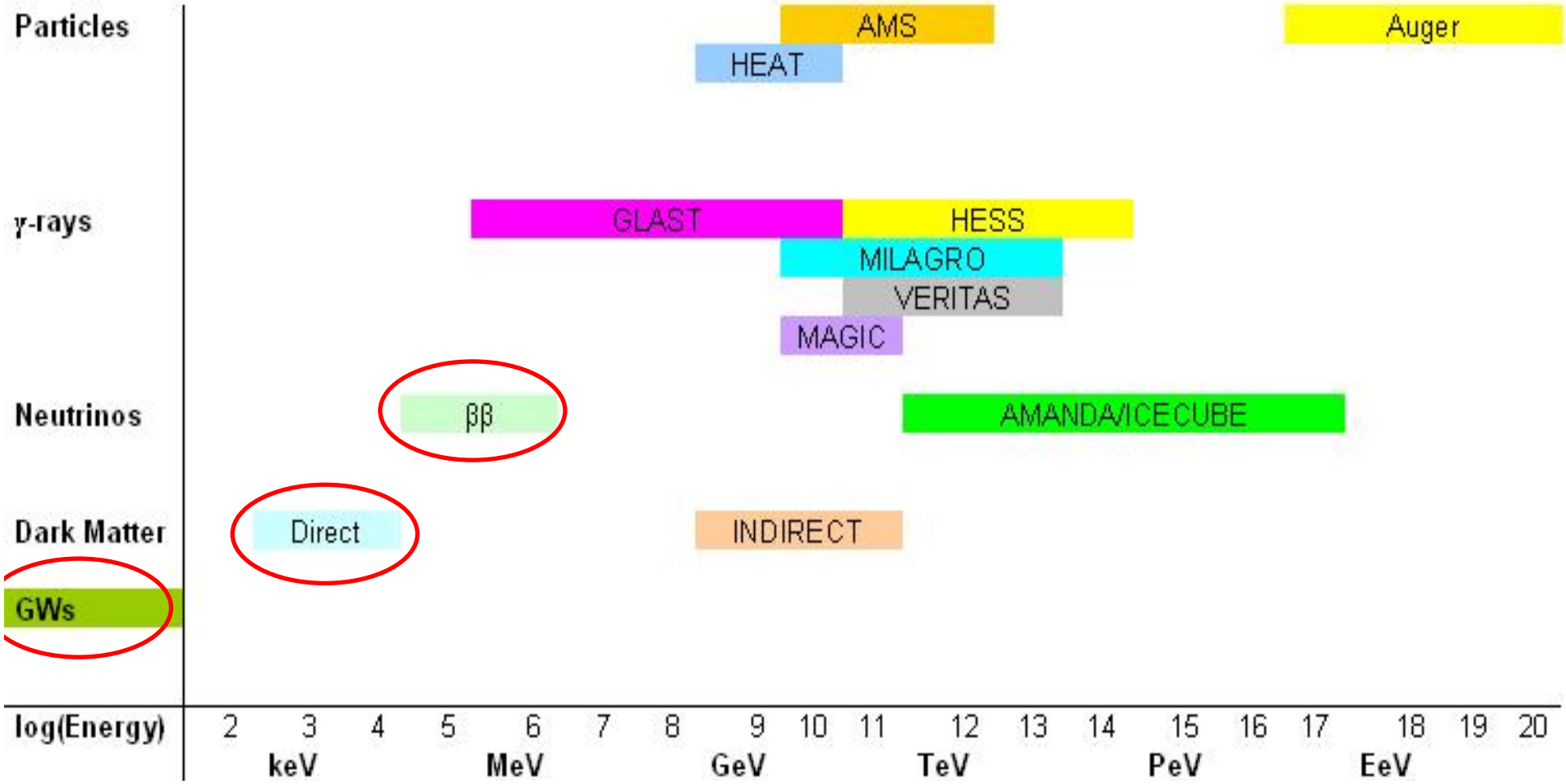
Imperial College London

PSD 7, Liverpool,
September 2005

Position Sensitivity?

- Imaging
  - Sky maps – ν/γ rays/cr?
  - Directionality – dm
- Event Characterisation
  - Particle identification – dm/cr
  - Event location (within detector) – dm, ββ
  - Calibration
- Motion Sensing
  - Scientific signal – gw

Astroparticle Physics Techniques span at least 20 orders of magnitude in energy and at least 5 different 'event' species!!!!



Cosmic Ray Particles

- AMS

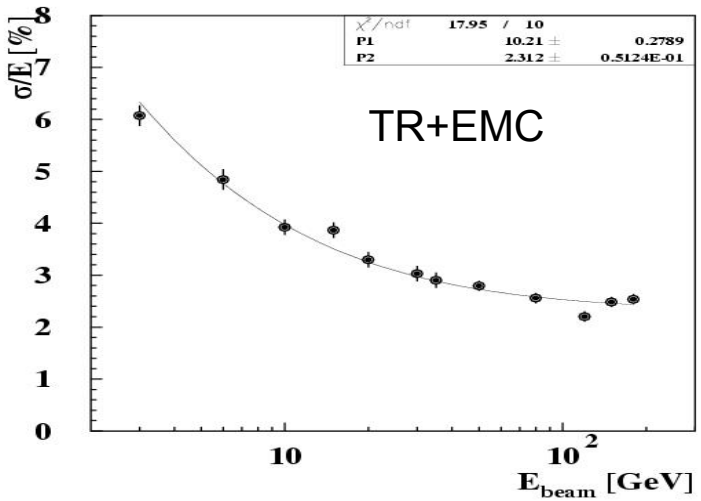
  Goals

  – Detection of primary cosmic-rays below the knee [~1GeV to 1TeV]

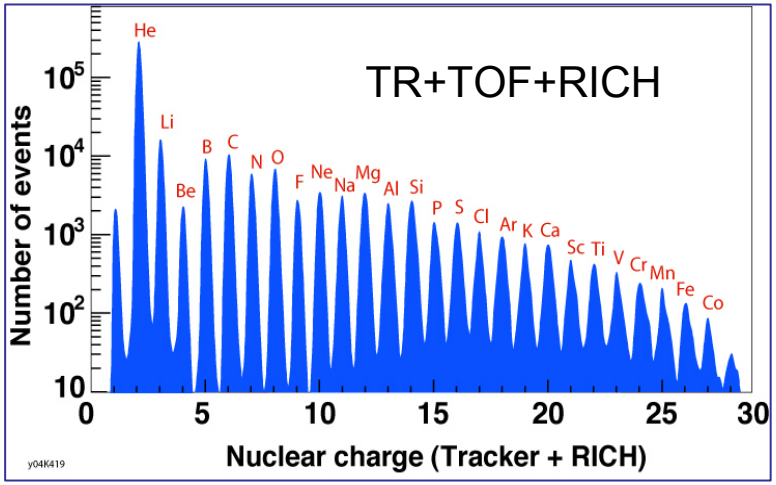
  – Good energy resolution

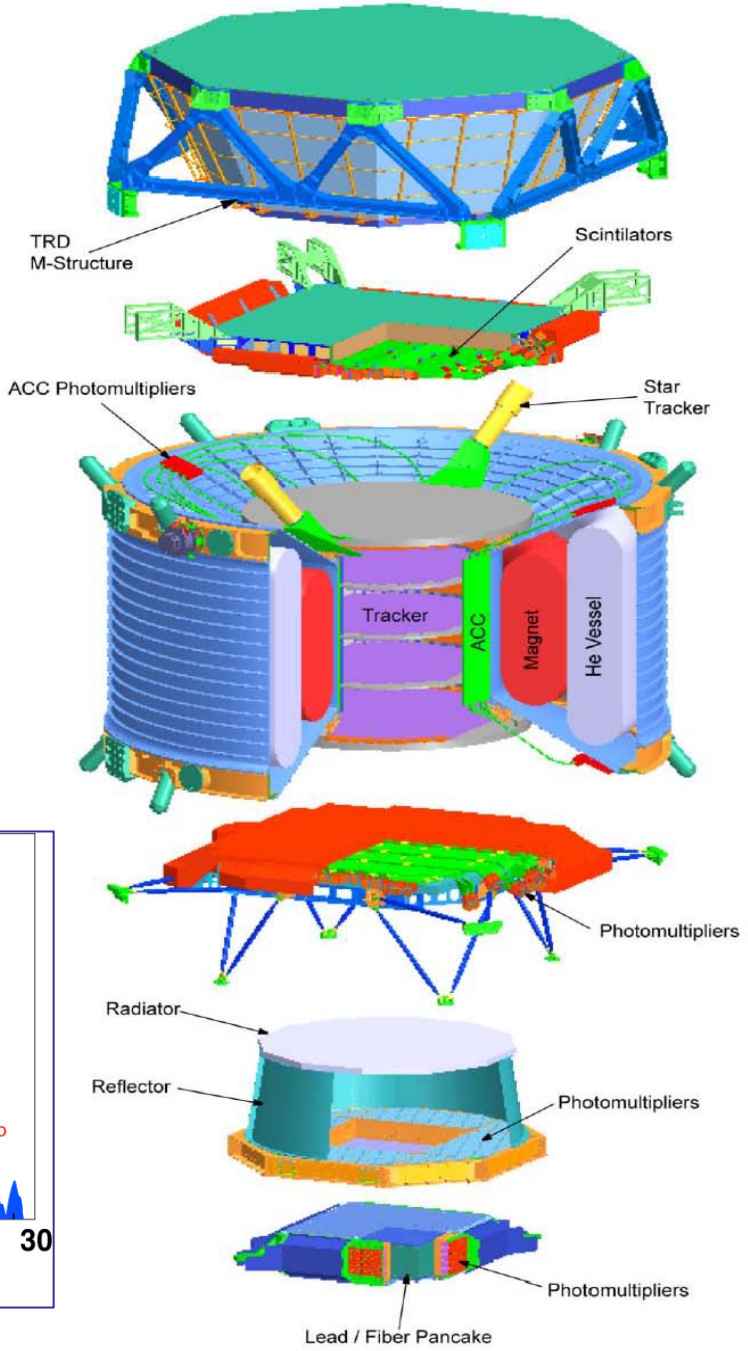
  – Good particle identification

  – Good statistics



$\Delta R/R \sim 1.5\%$ & $\Delta E/E \sim 3\%$





TRD:
Transition
Radiation
Detector

TOF: (s1,s2)
Time of Flight
Detector

MG:
Magnet

TR:
Silicon Tracker

ACC:
Anticoincidence
Counter

AST:
Amiga Star
Tracker

TOF: (s1,s2)
Time of Flight
Detector

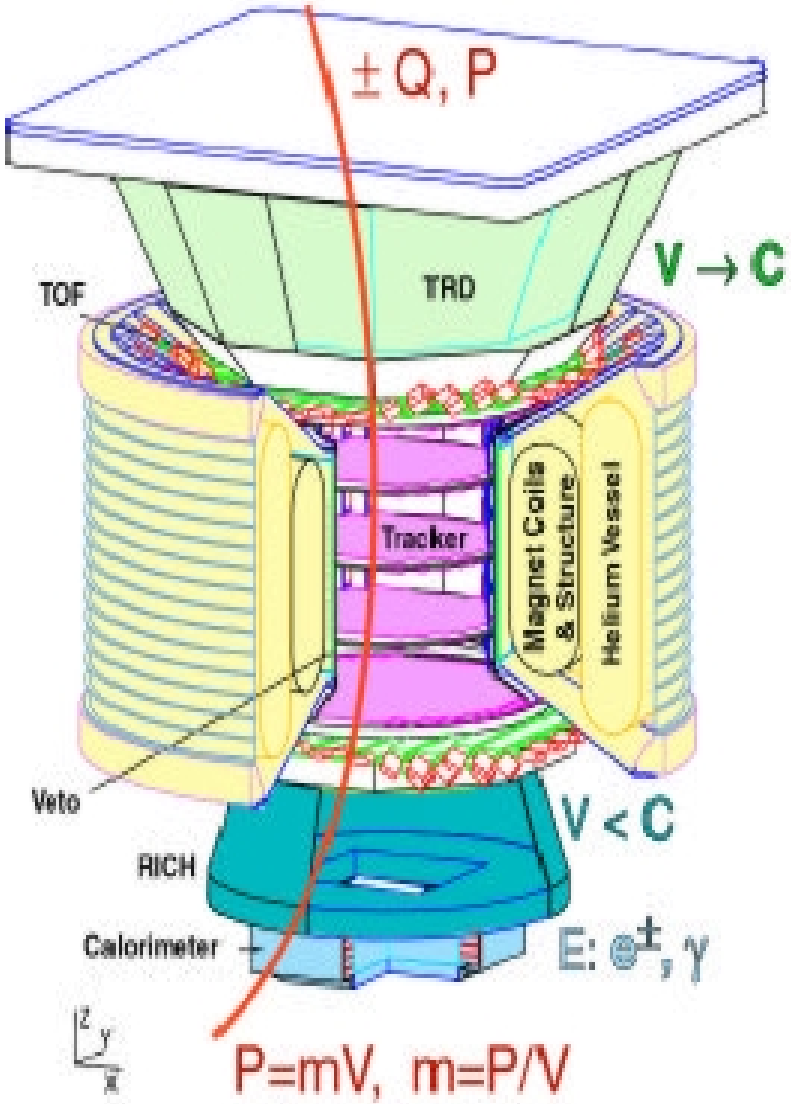
RICH:
Ring Image
Cherenkov Counter

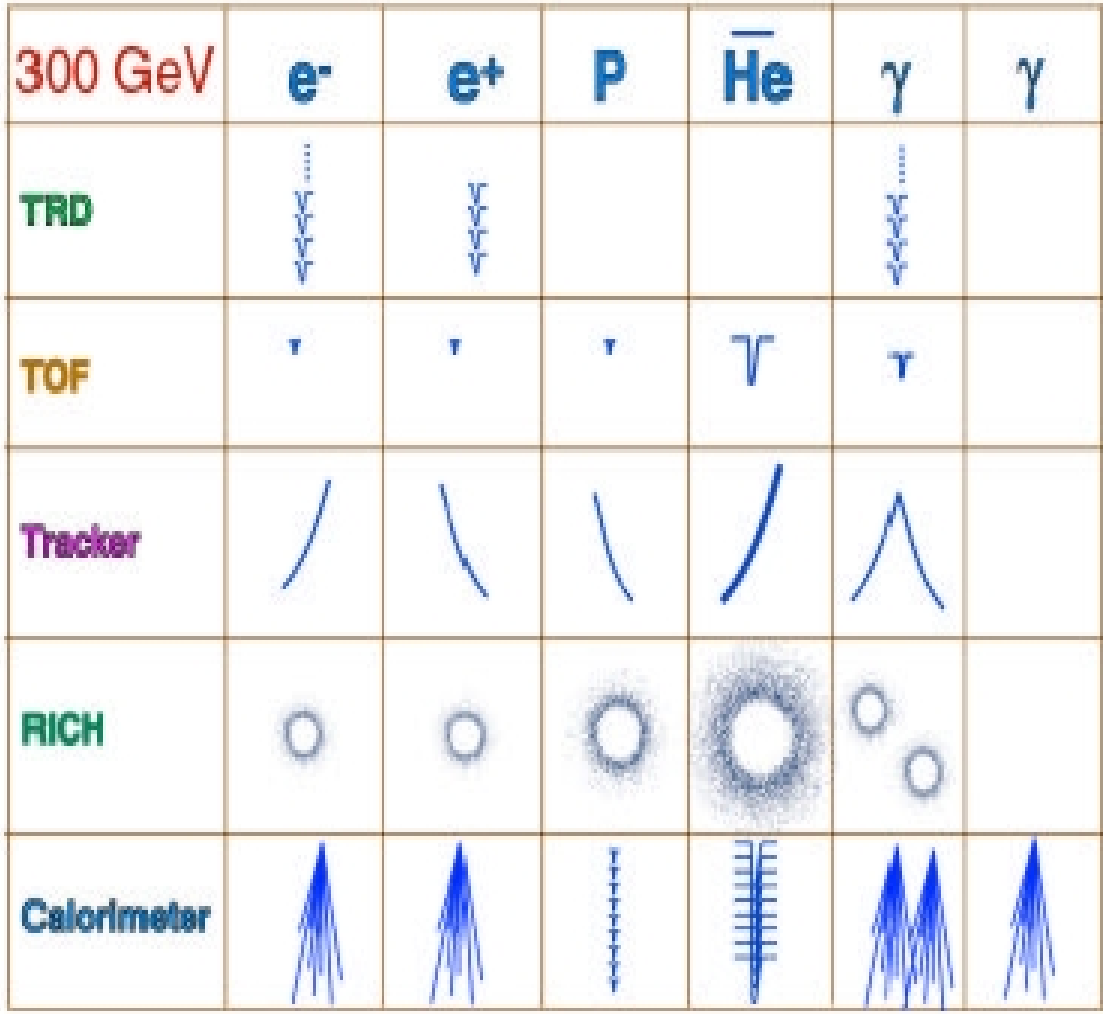
EMC;
Electromagnetic
Calorimeter

Imperial College
London

AMS Alpha Magnetic Spectrometer
Integration MIT

AMS-02



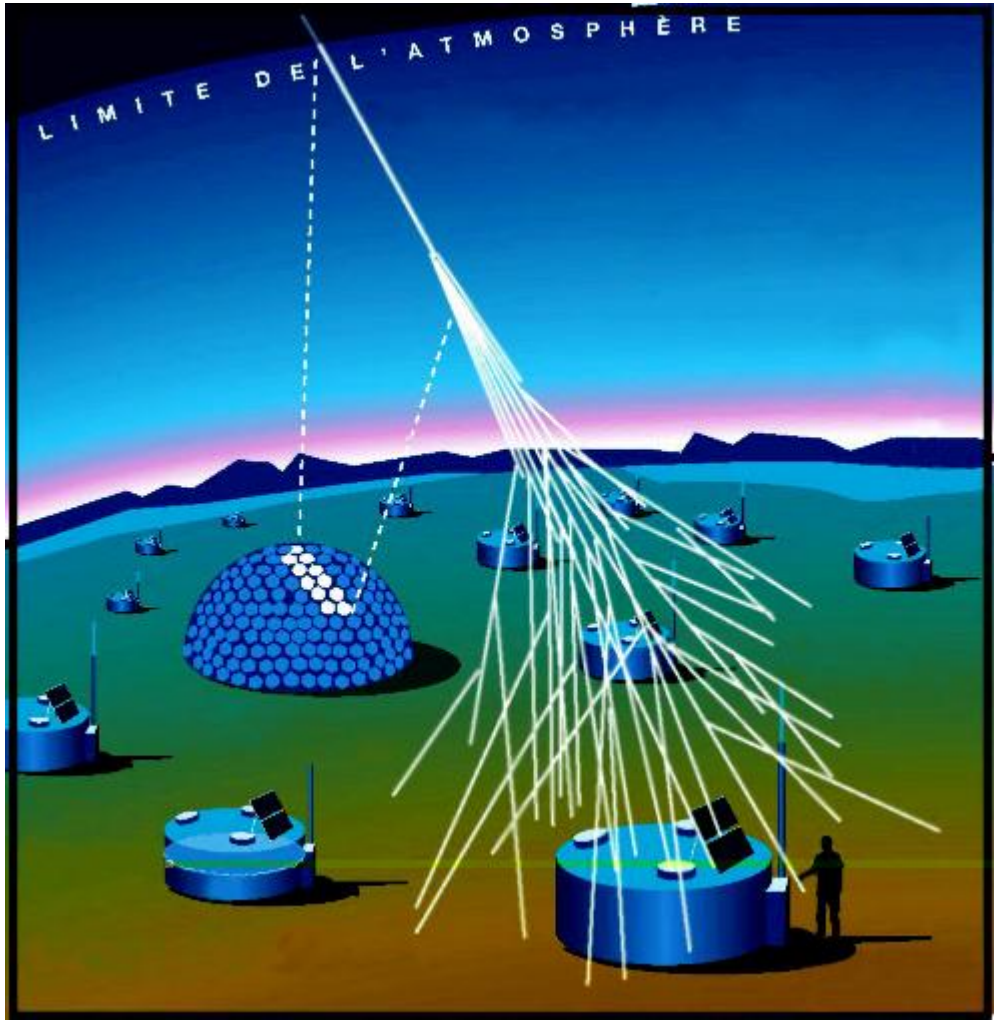


Imperial College London

PSD 7, Liverpool, September 2005

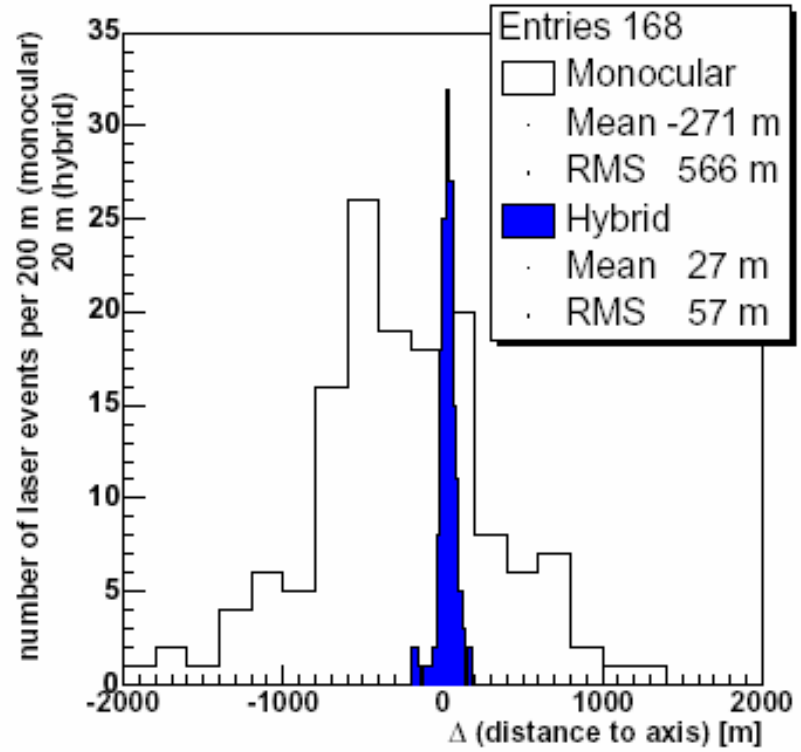
Cosmic Ray Particles

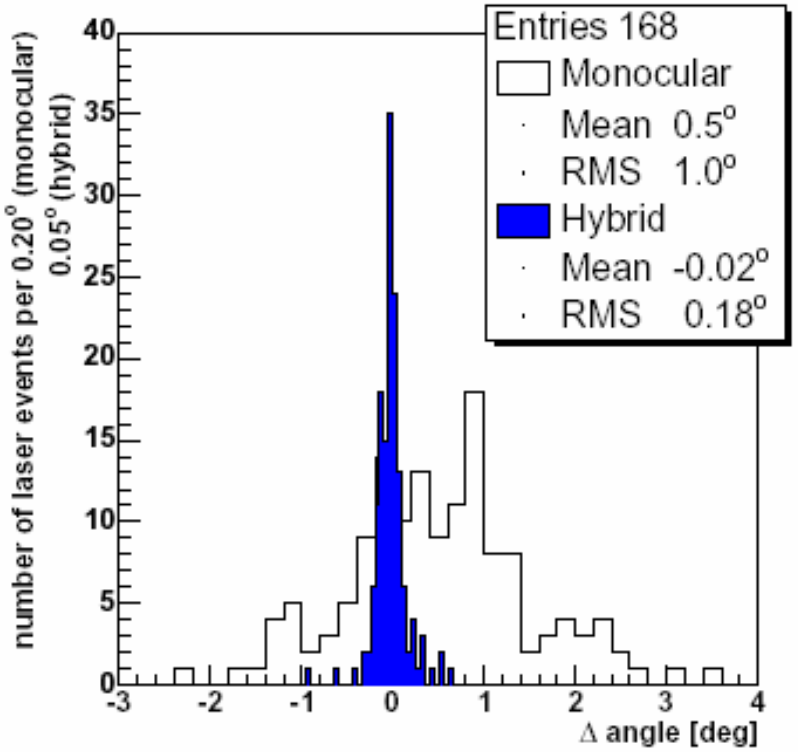
- Auger
  - Observation of ultra-high energy cosmic rays (~10^{20}eV)

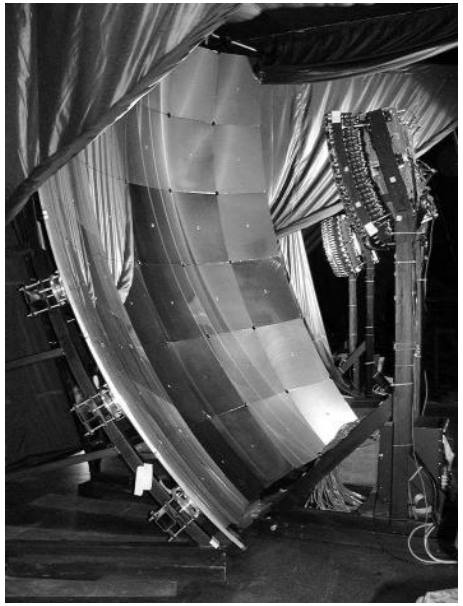


Pierre Auger Observatory

- Array of 1600 Surface Detectors (SD)
  - Cylindrical water Cherenkov tanks – 1.8m diameter x 1.5m tall viewed by 3 9” photomultipliers – on 1.5km grid.
  - Some ability to separate the electromagnetic and muon components.
- Array of 4 Fluorescence Detectors (FD)
  - Each FD has 6 telescopes with 3.5m mirrors and 440 PMTs in the focal plane. Each PMT is viewing 1.5^{o} diameter and the psf is ~ 0.5^{o}.







+

$\Delta E/E \sim 25\%$

γ-Rays

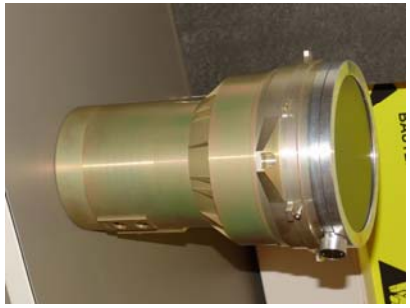
- GLAST

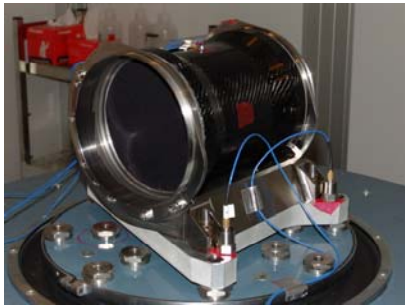
  Goals

  – Identify and measure the flux of gamma-rays with energy 20MeV to 300GeV - LAT

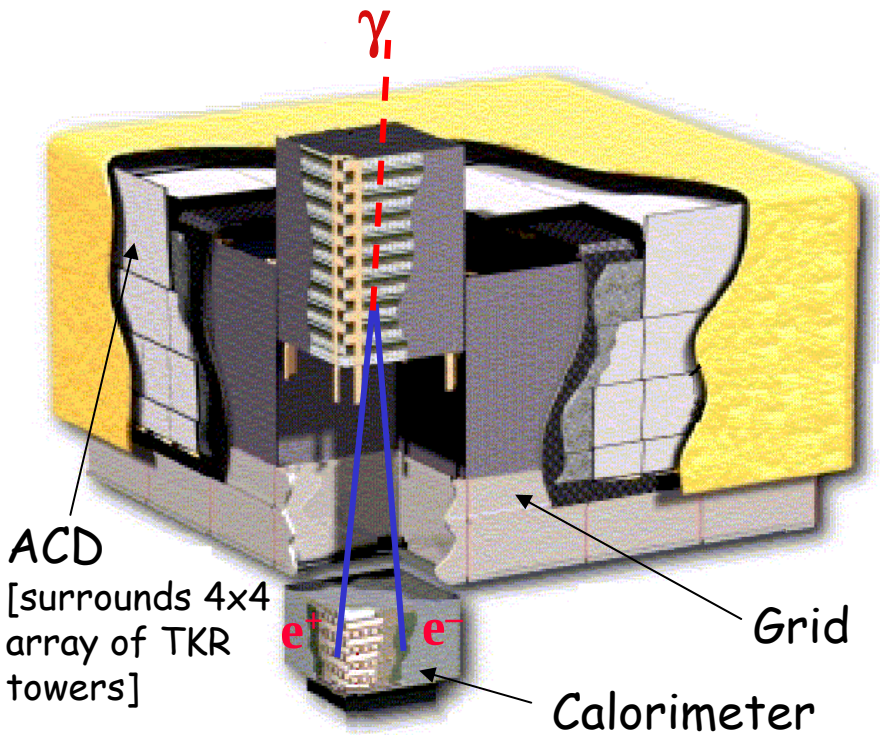
  – Gamma-ray burst spectra between 10keV and 30MeV - GBM

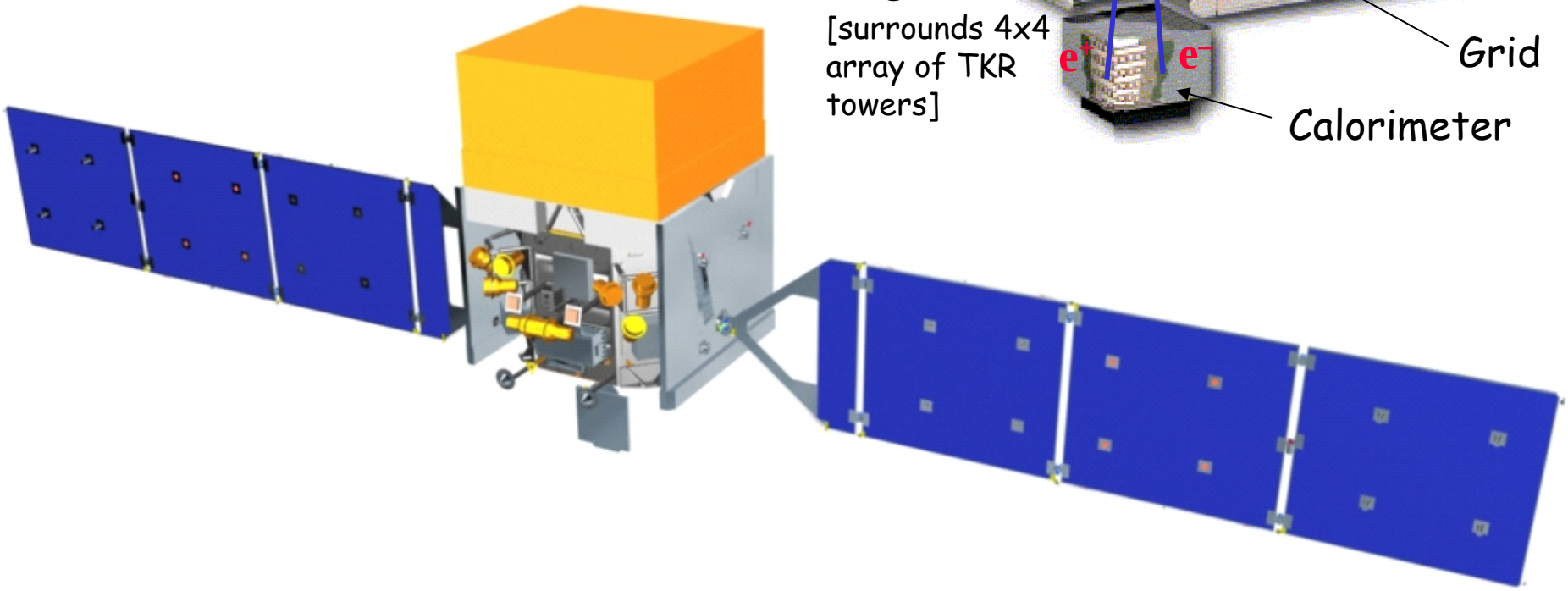
Imperial College London





pair conversion telescope



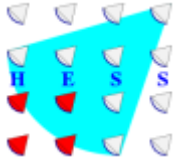


Quantity	Requirement	Minimum	EGRET
Mission Lifetime	>5 years	>2 years	
LAT High-latitude Point Source Sensitivity (E>100 MeV)	$<6x10^{-9}$ cm^{-2}s^{-1}	$<8x10^{-9}$ cm^{-2}s^{-1}	$\sim1x10^{-7}$ cm^{-2}s^{-1}
LAT High-latitude Source Location Benchmark	<0.5 arcmin	<1 arcmin	5 arcmin
LAT Peak Effective Area	>8000 cm^2	>8000 cm^2	1500 cm^2
LAT Energy Range	<20 MeV - > 300 GeV	<30 MeV - >100 GeV	20 MeV-30GeV
LAT Background Rejection	<10% high-latitude diffuse	<20% high-latitude diffuse	<1%
LAT Energy Resolution (on-axis, 100 MeV – 10 GeV)	<10%	<20%	10%
LAT Field of View	>2 sr	>1.5 sr	0.5 sr

Parameter	Requirement	Goal	Current Capability
Energy range	10 keV – 25 MeV	5 keV – 30 MeV	~8 keV – 30 MeV
Energy resolution	20% FWHM at 511 keV	(no stated goal)	~12% FWHM at 511 keV
Time resolution	10 microsecond	2 microsecond	2 microsecond
On-board GRB locations	15º accuracy (1σ radius) within 2 seconds	10º within 1 second	<15º; 1.8 seconds (<8º for S/C <60º zenith)
Rapid ground GRB locations	5º accuracy (1σ radius) within 5 seconds	3º within 1 second	TBD by analysis (scattering influenced)
Final GRB locations	3º accuracy (1σ radius) within 1 day	(no stated goal)	TBD by analysis (scattering influenced)
GRB sensitivity (on ground)	0.5 photons cm^{-2} s^{-1} (peak flux, 50–300 keV)	0.3 photons cm^{-2} s^{-1} (peak flux, 50–300 keV)	~0.4 photons cm^{-2} s^{-1} (peak flux, 50–300 keV)
GRB on-board trigger sensitivity	1.0 photons cm^{-2} s^{-1} (peak flux, 50–300 keV)	0.75 photons cm^{-2} s^{-1} (peak flux, 50–300 keV)	0.71 photons cm^{-2} s^{-1} (peak flux, 50–300 keV
Field of view	8 steradians	10 steradians	9.5 steradians
Deadtime	<10 μs/count	<3 μs/count	~2 μs/count

γ-Rays

- HESS



Goals

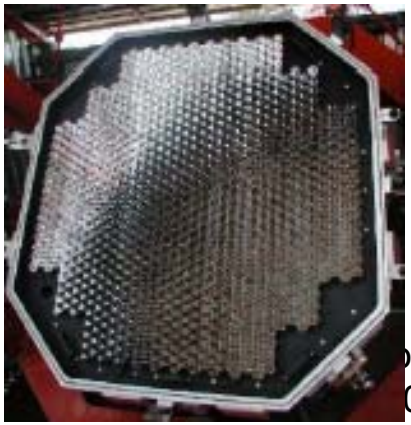
– γ-ray astronomy above 100 GeV

Technique

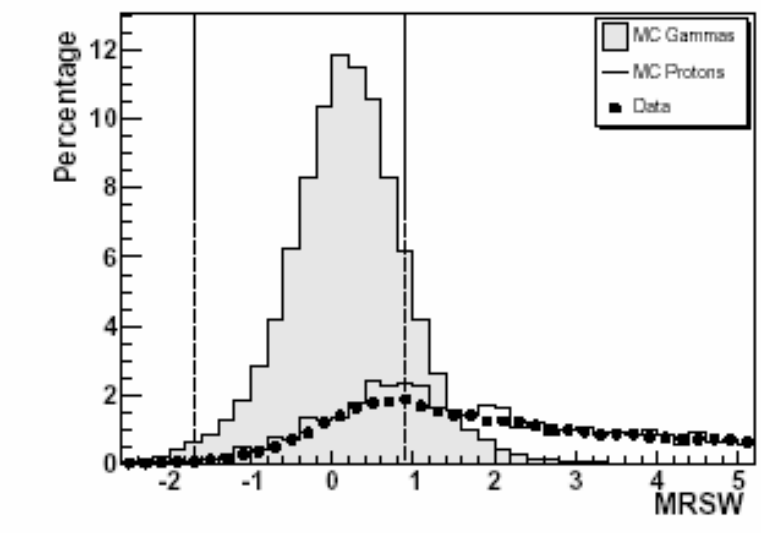
– Air Cherenkov imaging

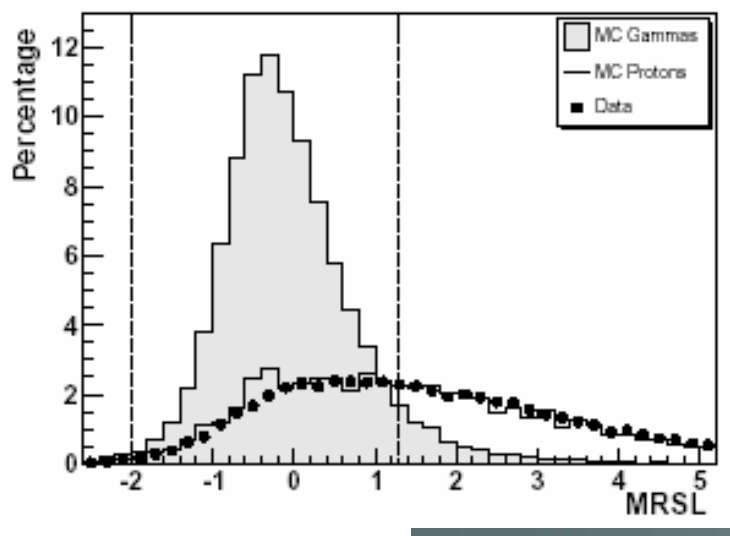
γ-Rays

- Four identical telescopes
  - Davies-Cotton reflector with a flat-to-flat width of 13m and a focal length of 15 m.
  - mirror is segmented into 382 round (60 cm diameter) front-aluminized glass mirrors.
  - psf (<0.1^{o}) across the whole 5^{o} field of view.
  - 960 photomultiplier pixels subtending 0.16^{o} each, with Winston cone light concentrators.



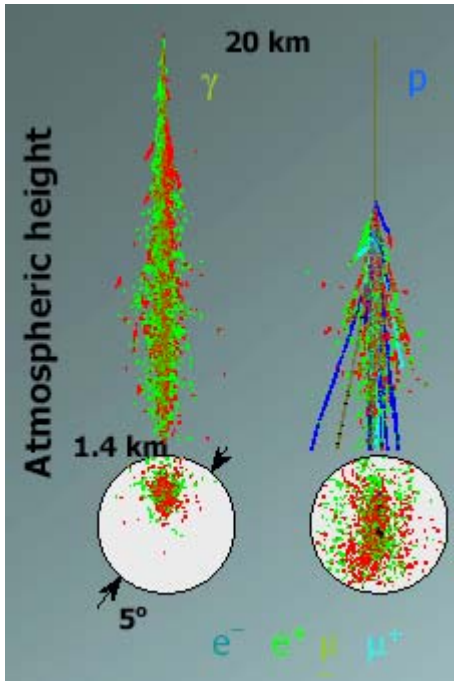
γ-Rays





Background rejection (cosmic-rays!) requires good image recovery

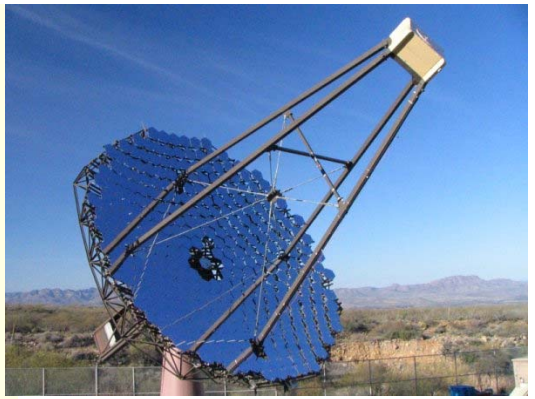
$\Delta E/E \sim 15\%$



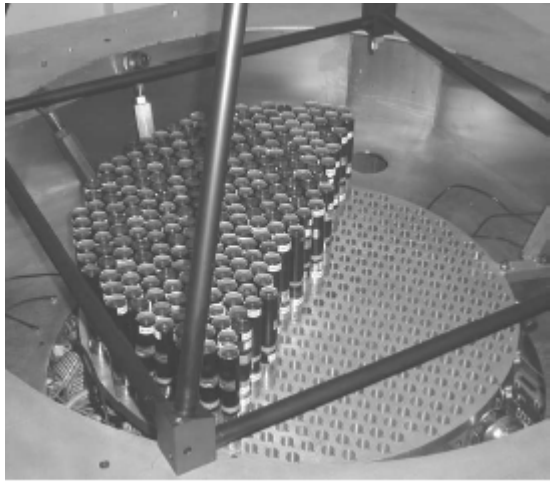
Imperial College London

VERITAS

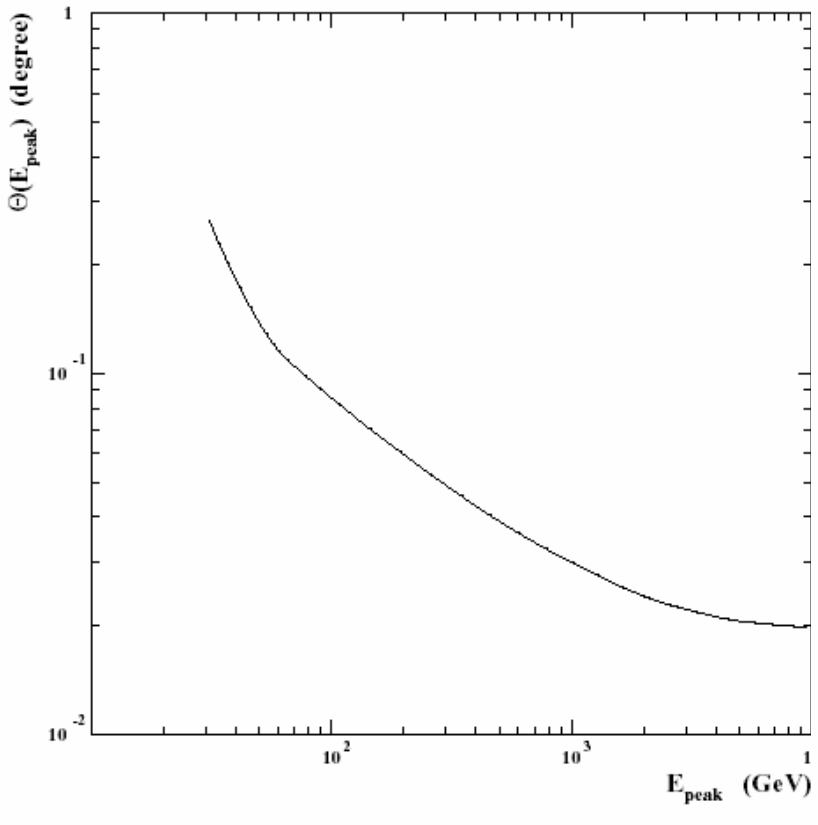
Very Energetic Radiation Imaging Telescope Array System

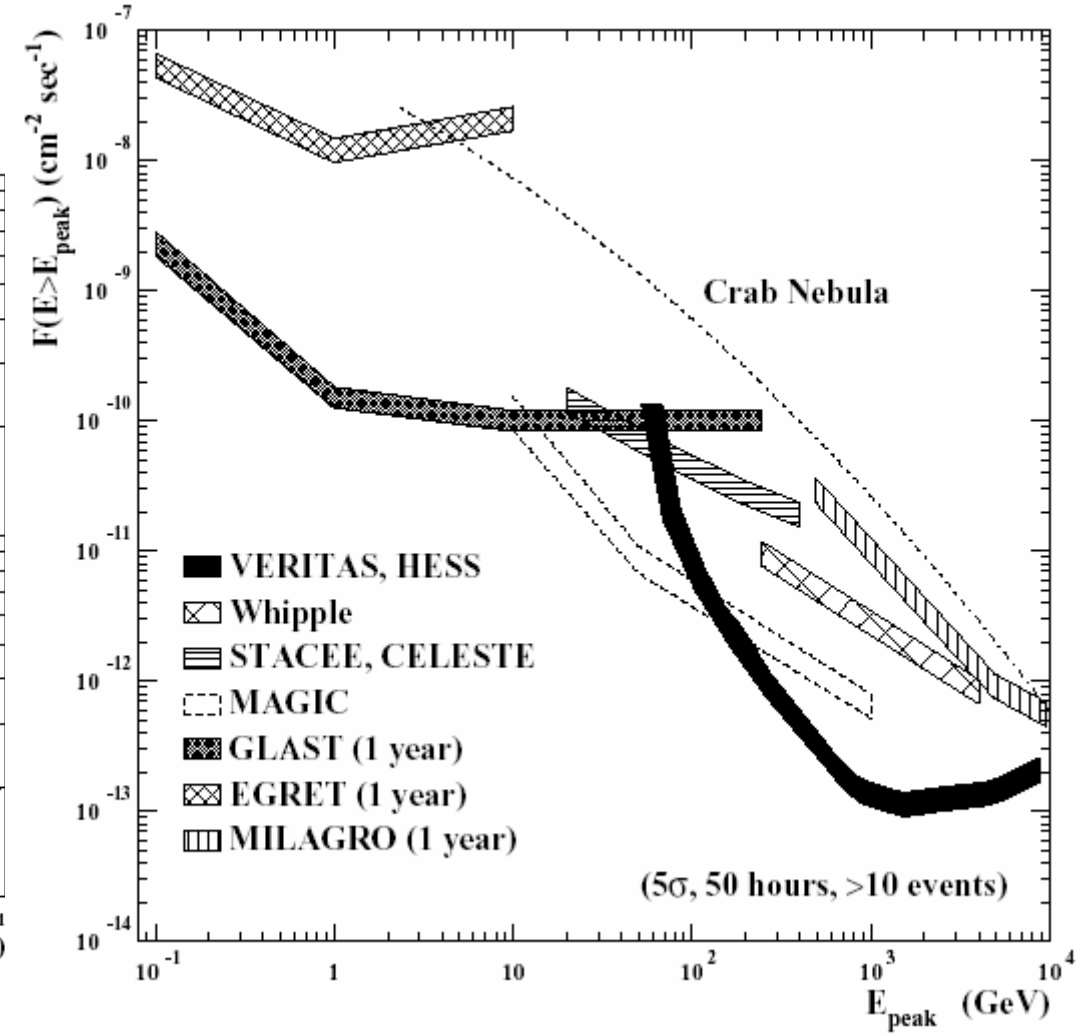


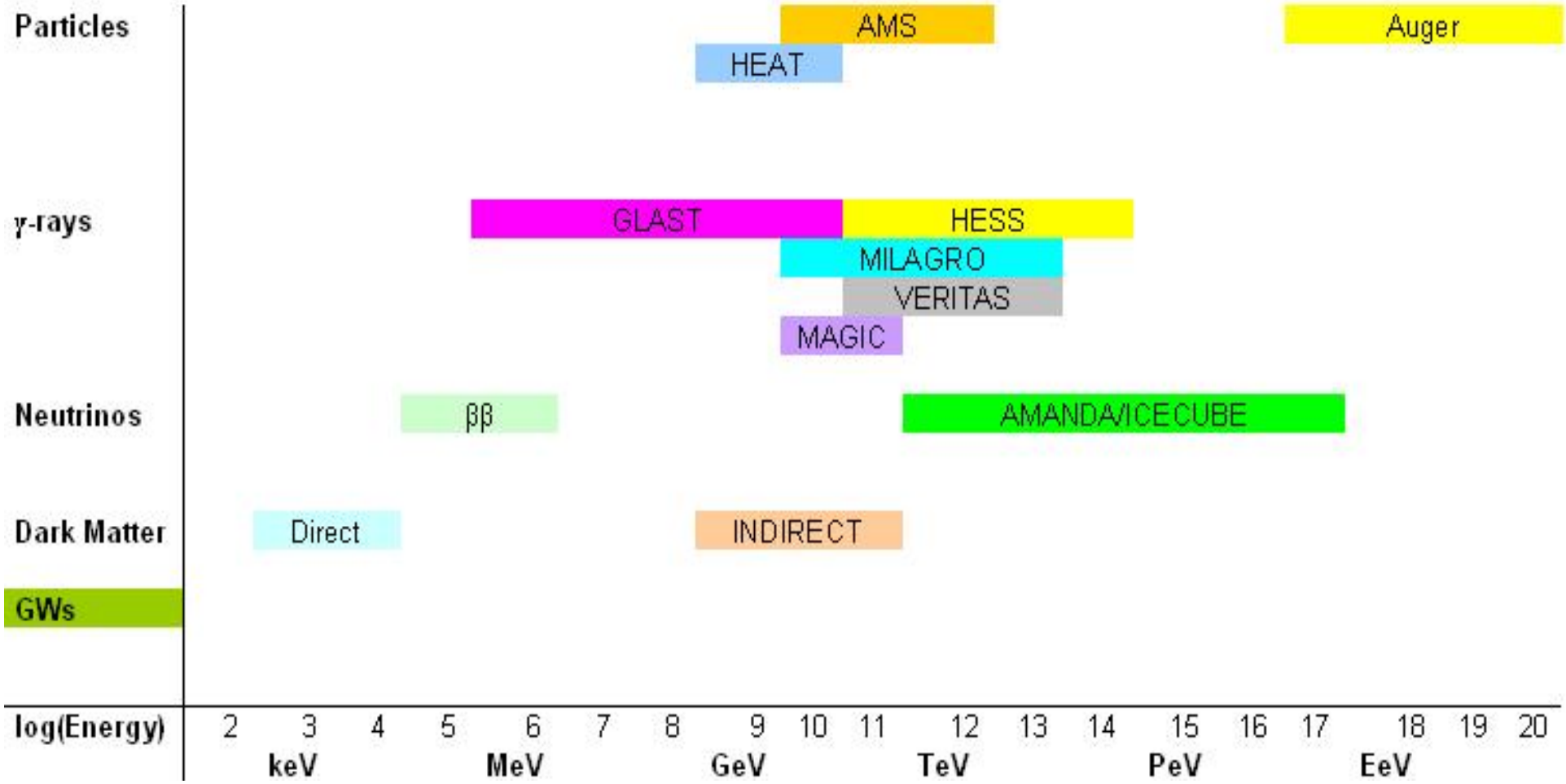
- Seven identical telescopes
  - Davies-Cotton 12m with f/1.0.
  - mirror is segmented into 315 hexagonal elements.
  - psf (<0.1^{o}) across the whole 3.5^{o} field of view.
  - 499 photomultiplier pixels with 0.15^{o} spacing.



Imperial College London


Θ(E_peak) (degree)
E_peak (GeV)


F(E>E_peak) (cm^-2 sec^-1)
Crab Nebula
VERITAS, HESS
Whipple
STACEE, CELESTE
MAGIC
GLAST (1 year)
EGRET (1 year)
MILAGRO (1 year)
(5σ, 50 hours, >10 events)
E_peak (GeV)

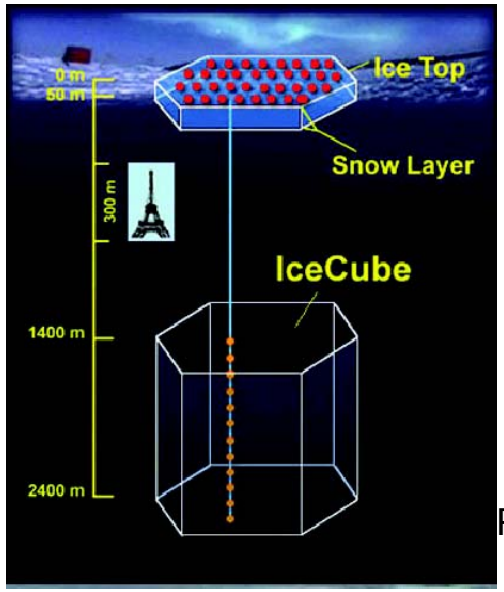


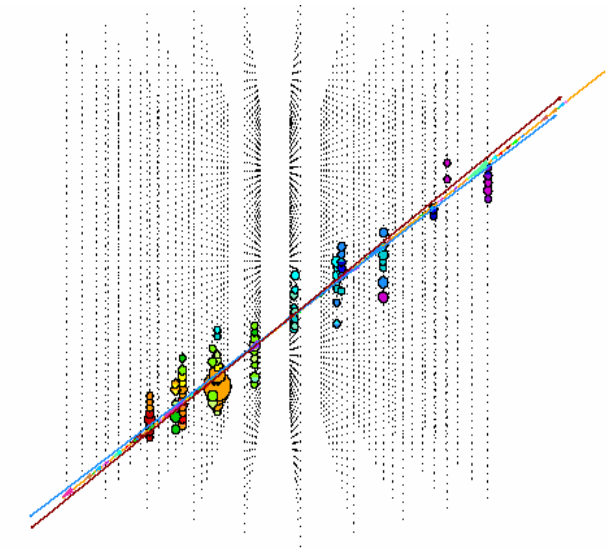
Imperial College London

PSD 7, Liverpool, September 2005

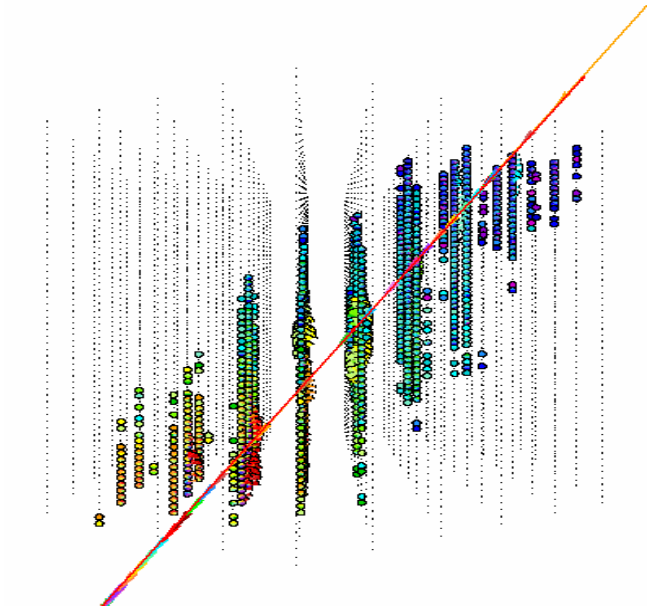
Neutrinos

- ANTARES/AMANDA/BAIKAL/ICECUBE/ NEMO/NESTOR
  - Measure Cherenkov light from relativistic muon created by incoming neutrino.
  - Arrays of photodetectors widely spaced in medium (water/ice)

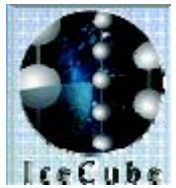


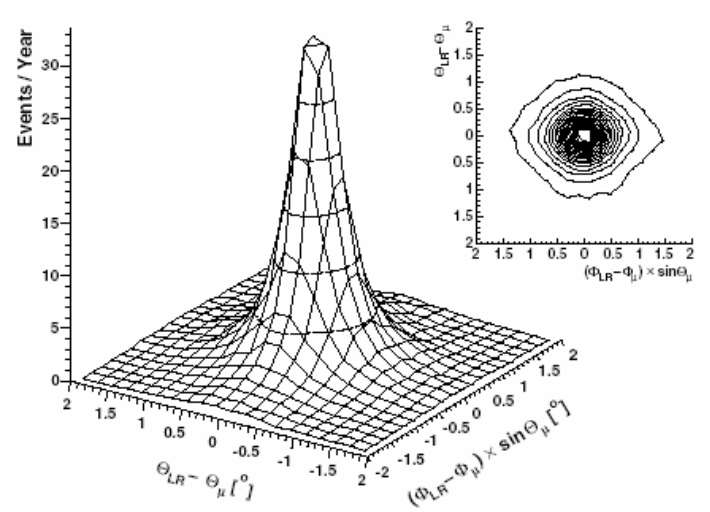


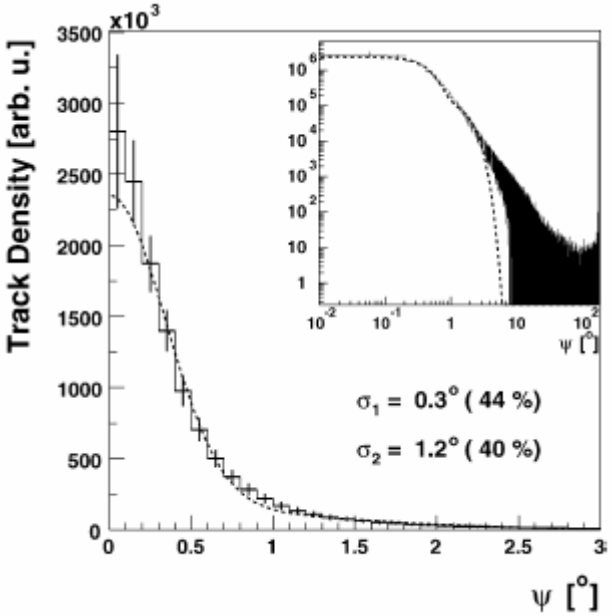
10 TeV μ



6 PeV μ



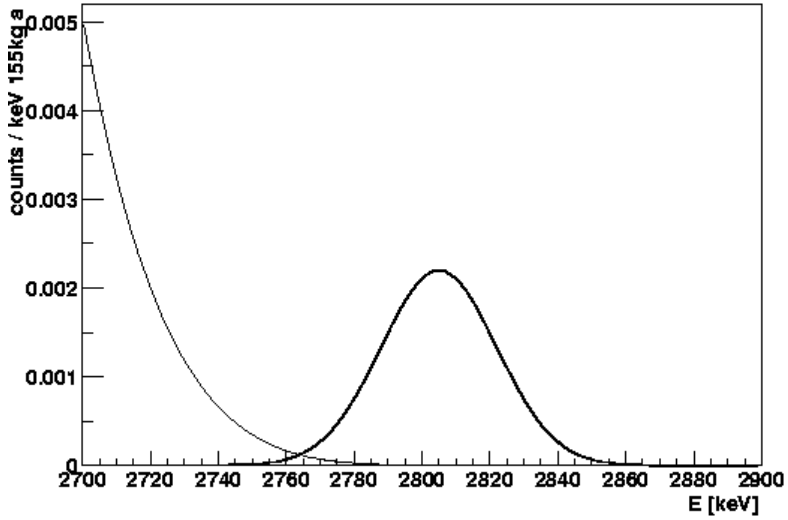




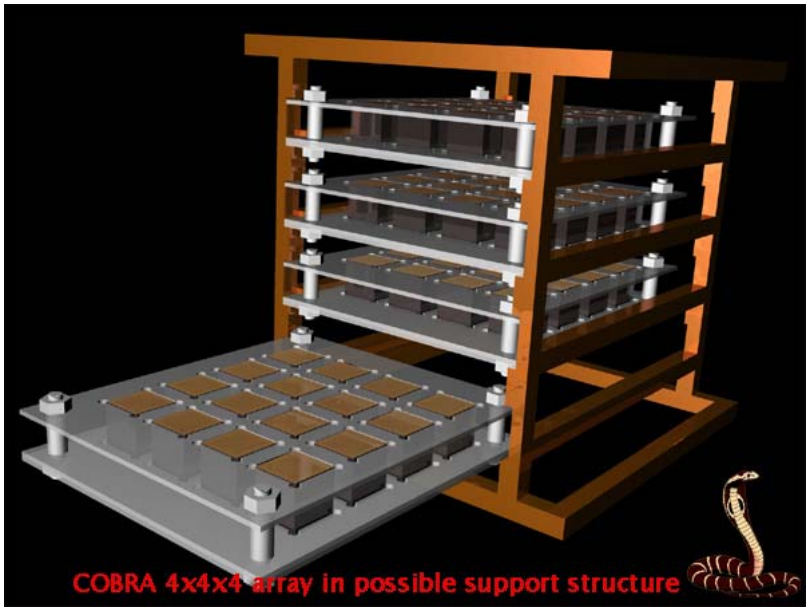
Imperial College London

[No] Neutrinos – Double beta decays

- Measure total energy spectrum of decay electrons – EXO, Majorana, Cuore, Gerda, COBRA ⇒ good spectral resolution in large mass detectors
- Measure tracks of decay electrons – Super-NEMO, COBRA?



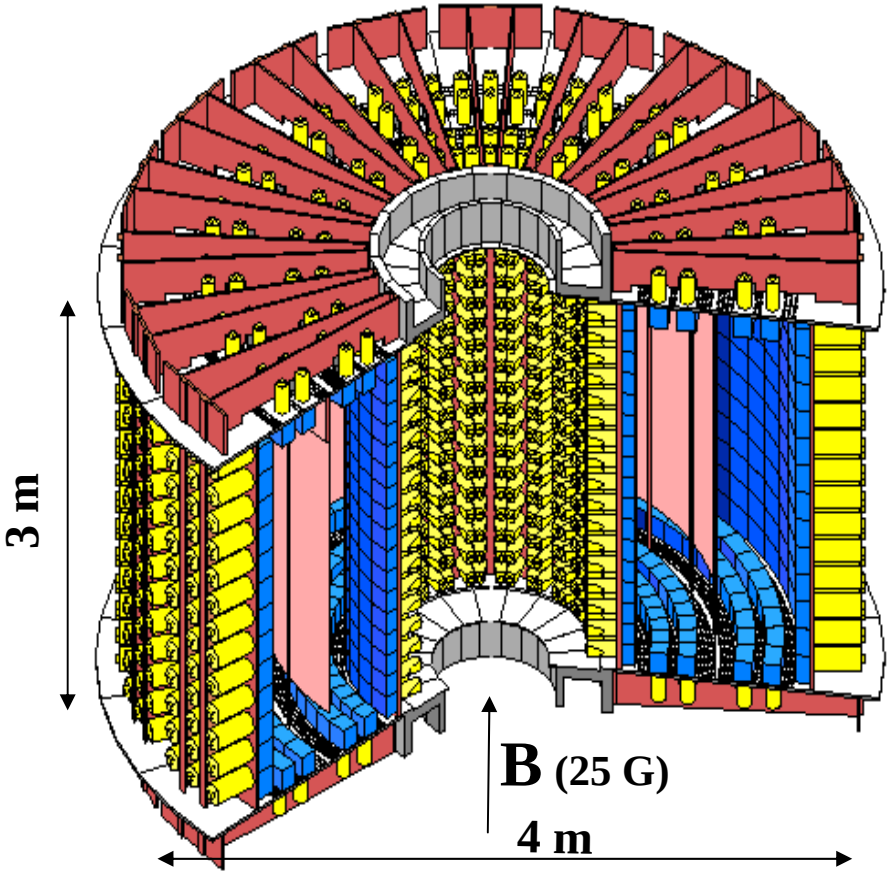
Imperial College London



Talk by Fulton

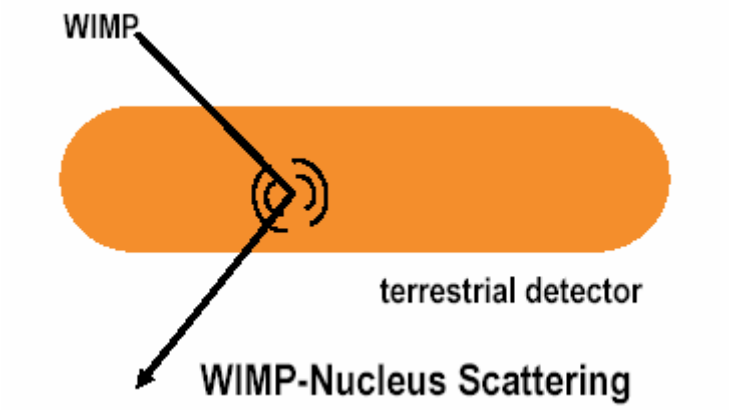
In this session

20 sectors



Direct Dark Matter Detection

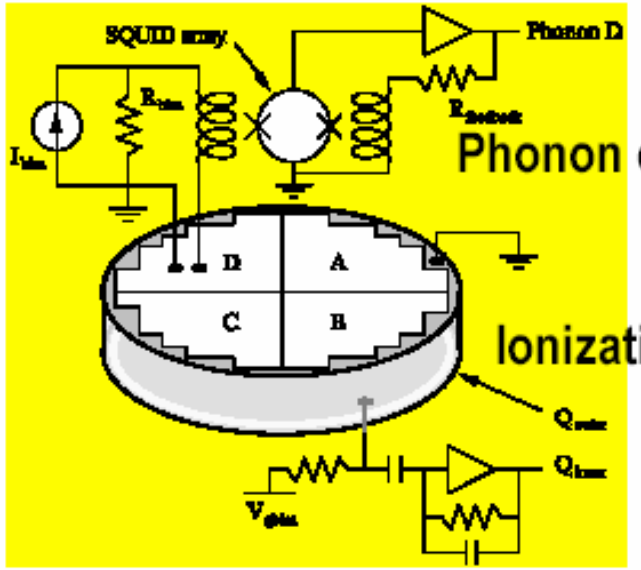
- Requirements
  - Detect rare elastic nuclear recoil scattering events with $\Delta E \sim 1 = 10 keV$ with expected rates 10^{-5} to 10^{-1} /kg/day.
  - Reject backgrounds from electron recoils and neutron induced nuclear recoils.
  - Identify signatures of Galactic particles

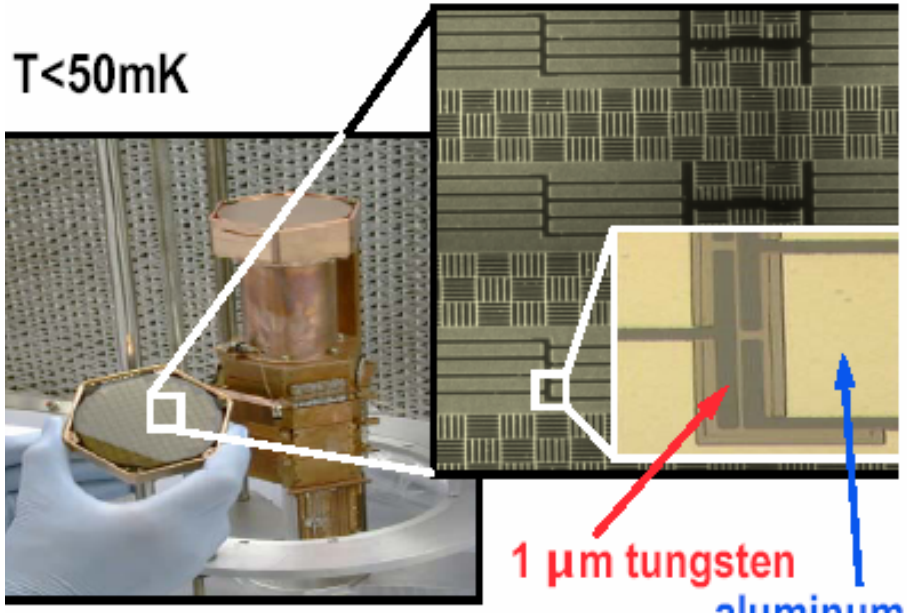


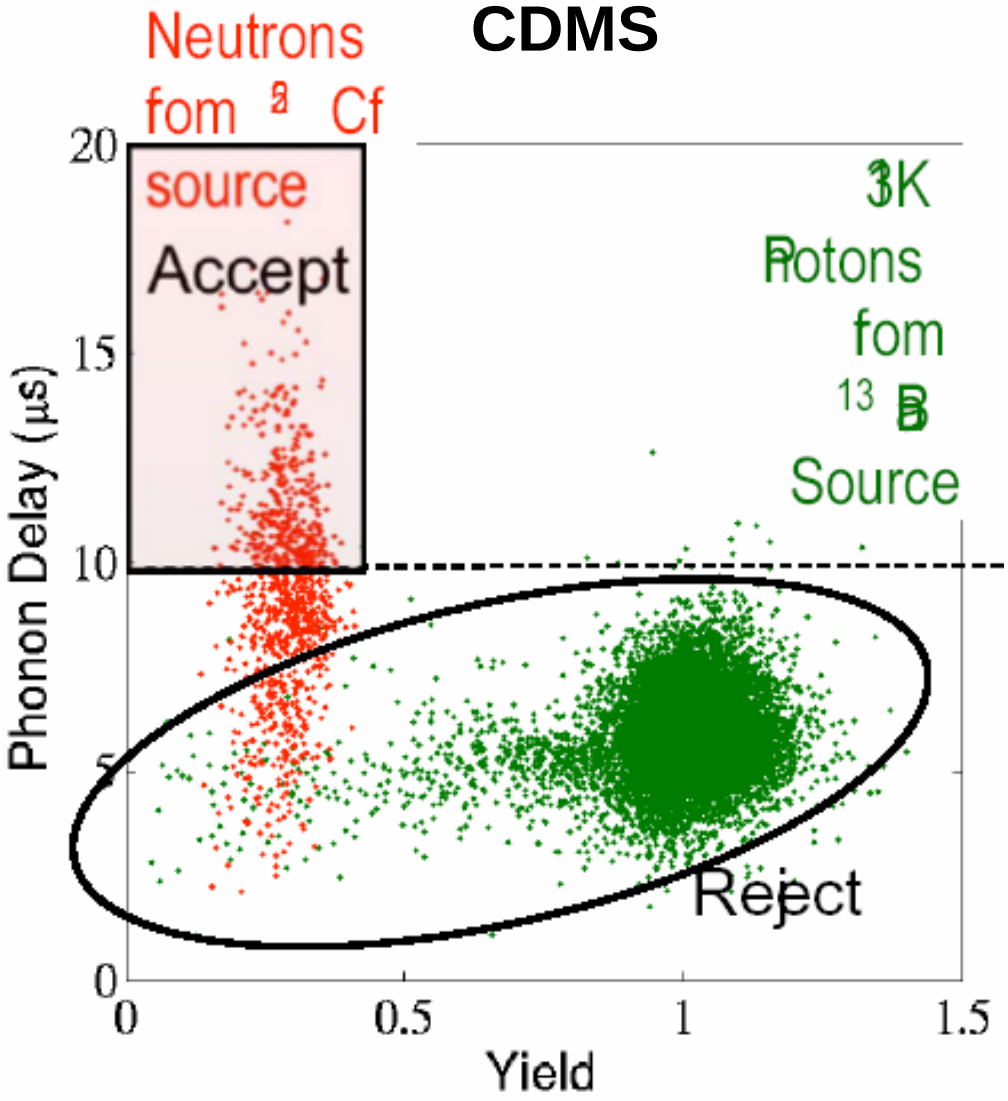
Direct Dark Matter Detection

- Techniques
  - Ionisation detectors – Germanium, DRIFT
  - Scintillators – CRESST I, ZEPLIN I
  - Phonons/Ionisation – CDMS, EDELEISS
  - Phonons/scintillation – CRESST II
  - Scintillation/Ionisation – ZEPLIN II/III, XENON
  - Others

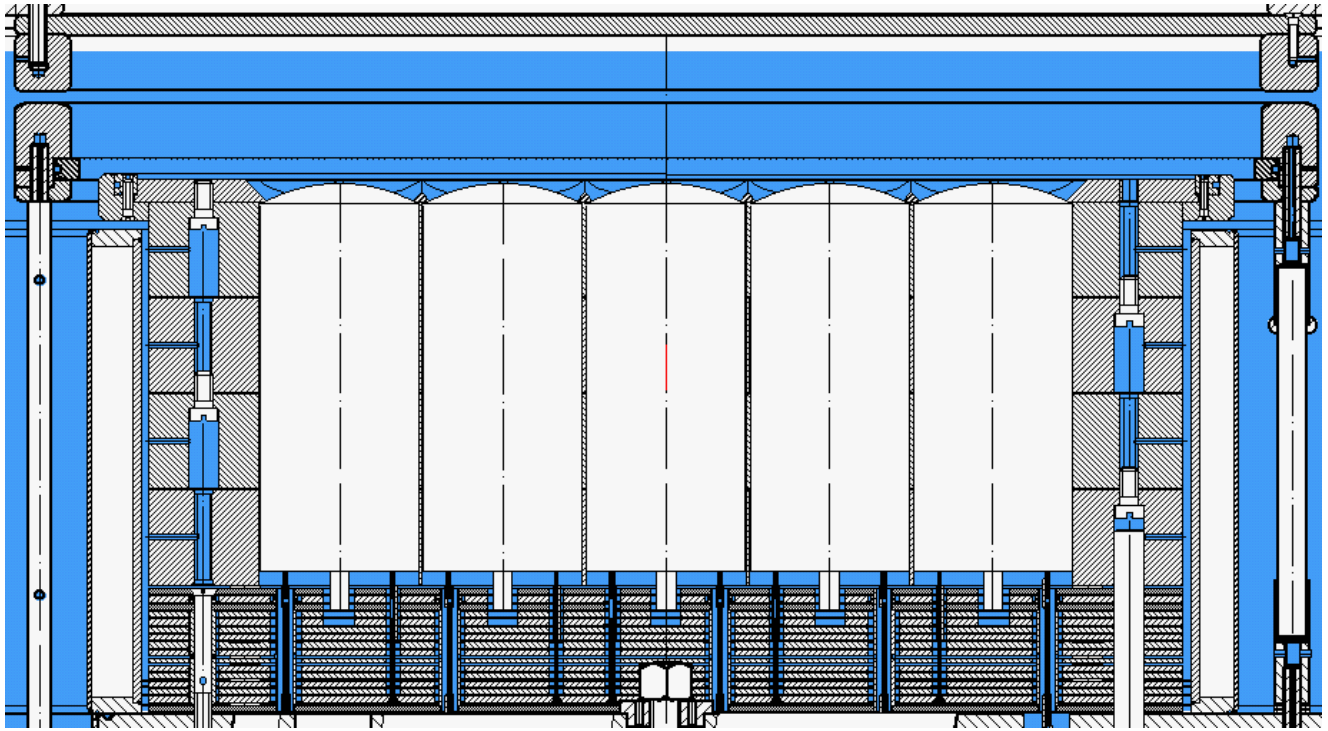
CDMS

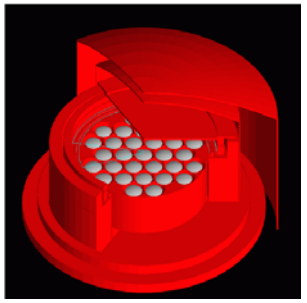






Position sensitivity defines fiducial volume





ZEPLIN III

Position sensitivity defines fiducial volume and gives multi-site rejection

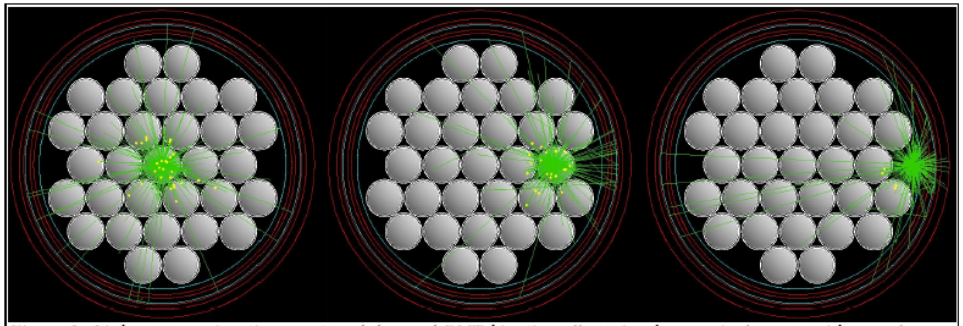
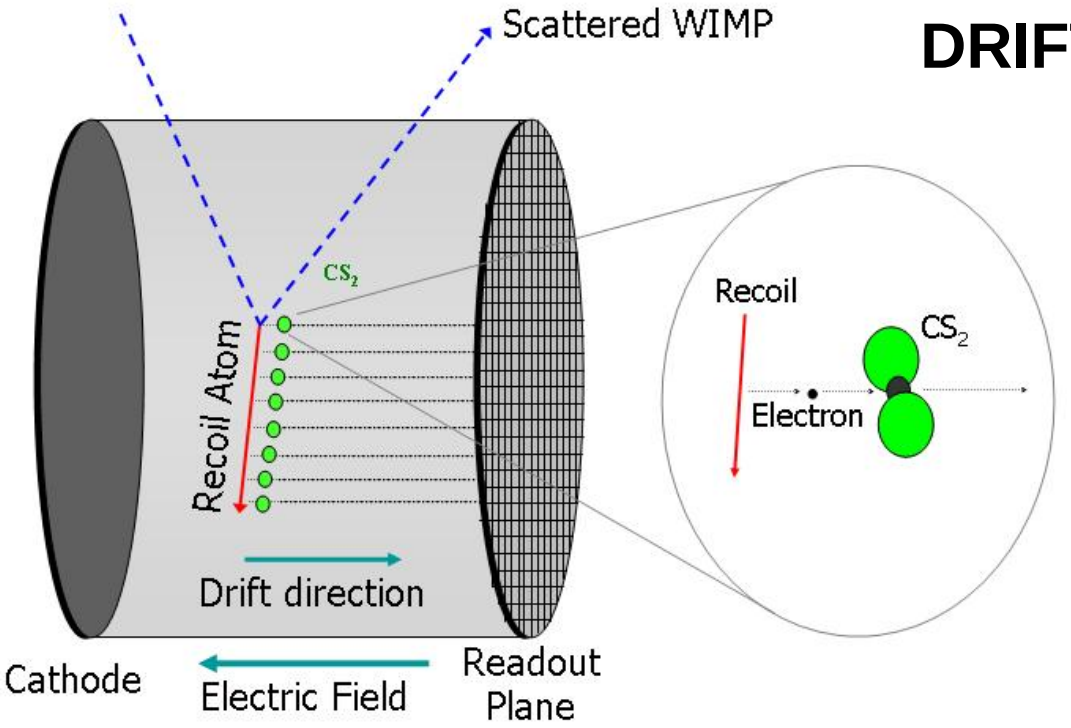


Figure 2: Light propagation (in green) and detected PMT hits (in yellow) for three typical events with one electron extracted from the liquid at different radii.

Talk by Lindote – this session

Poster by Solovov

DRIFT



Ionisation electrons rapidly attach to CS_2 molecules and these are drifted to read-out plane. High-field detaches electrons which are then detected in proportional gain mode using fine wire read-out

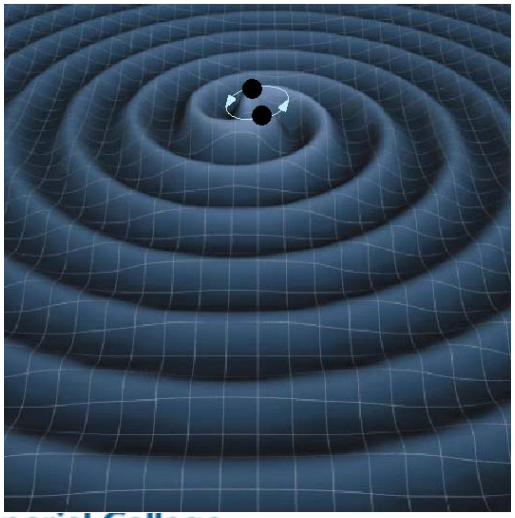
- **Discrimination from 'range' vs energy**
- **Directionality from TPC (axis) + dE/dx (sense)**
  - ➢ ***x*, *y* from crossed read-out wire grids (DRIFT I and II)**
  - ➢ ***z* from event time duration as it crosses readout plane**

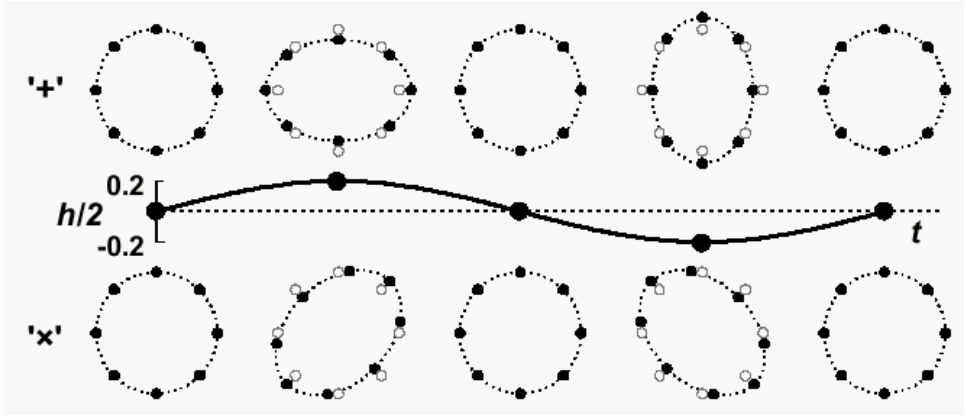
Talk by Hiroyuki – this session

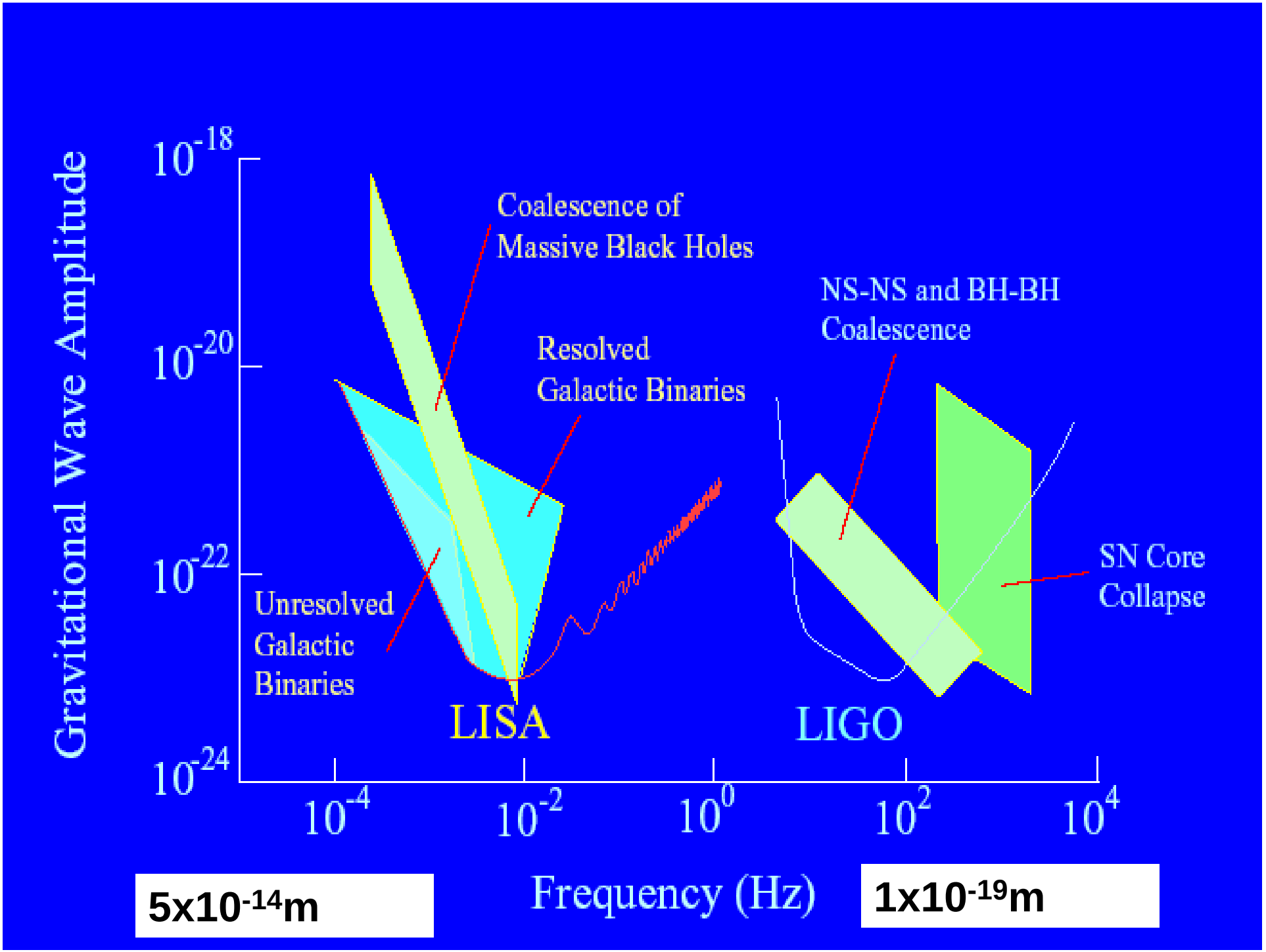
Poster by Ghag/Plank

Gravitational Wave Detection

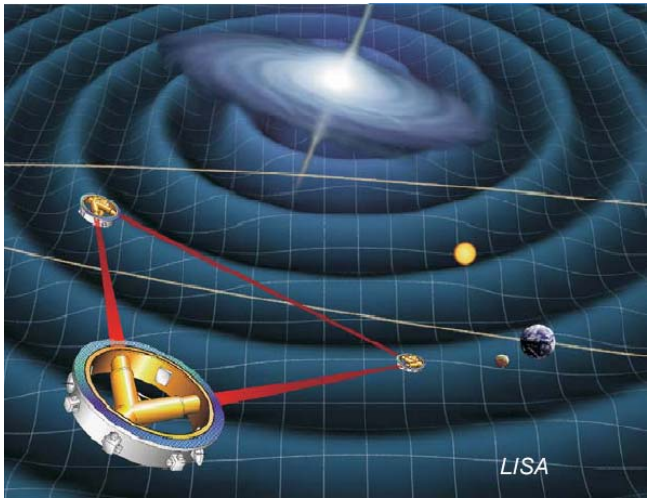
- Requirements
  - Detect waves in space-time through strain induced in measurement systems, $\Delta L/L$.
  - Measure temporal behaviour of $\Delta L/L$
  - Unravel signals from all sources seen together.






Gravitational Wave Amplitude
10^{-18}
10^{-20}
10^{-22}
10^{-24}
Coalescence of
Massive Black Holes
Resolved
Galactic Binaries
Unresolved
Galactic
Binaries
LISA
NS-NS and BH-BH
Coalescence
SN Core
Collapse
LIGO
10^{-4}
10^{-2}
10^{0}
10^{2}
10^{4}
Frequency (Hz)
5x10-14m
1x10-19m

Talk by Lockerbie – this session



The ultimate psds!!