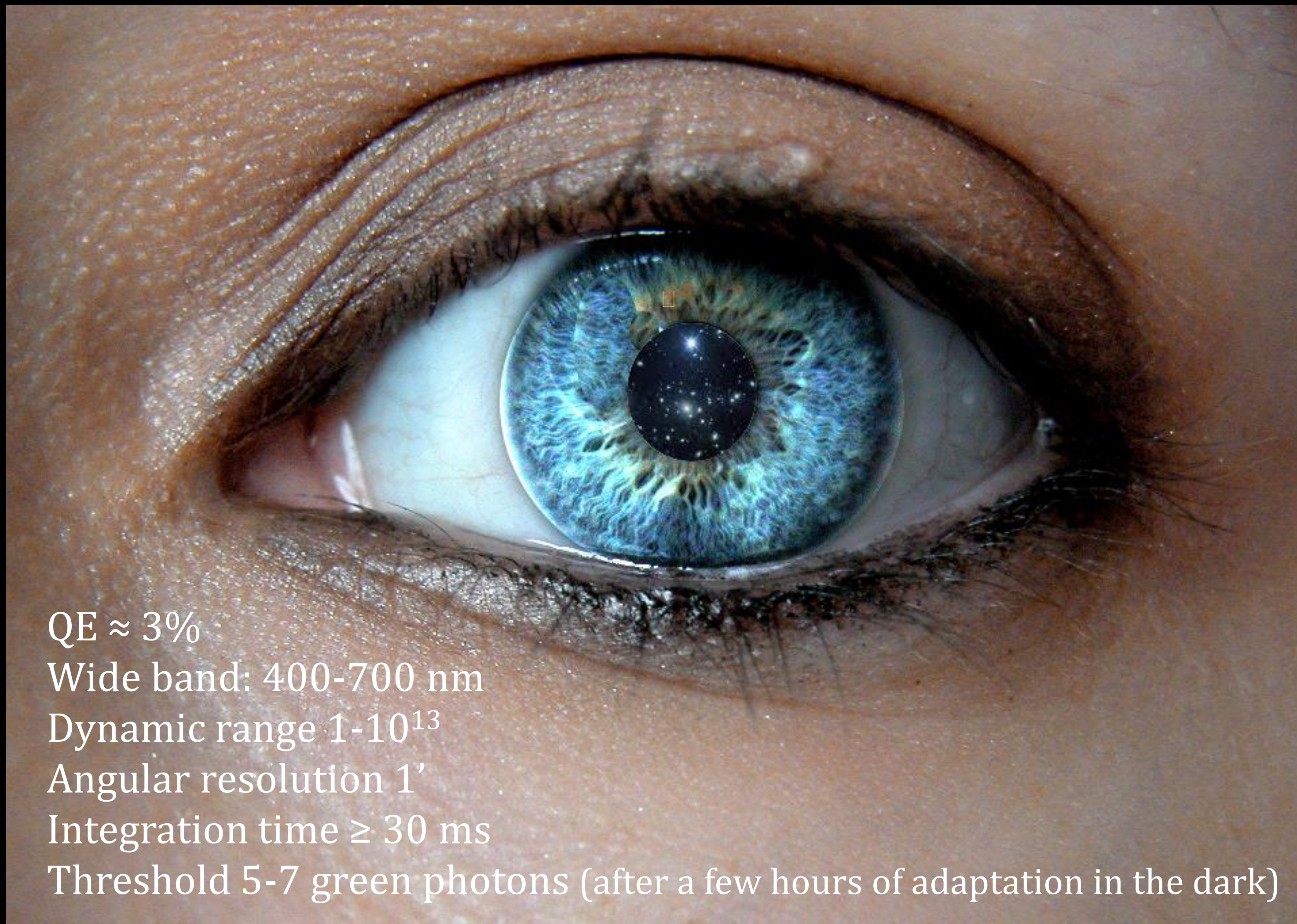
APPEC

Astroparticle Physics And Photodetection

New methods in Photodetection , Tours, 3 July 2014

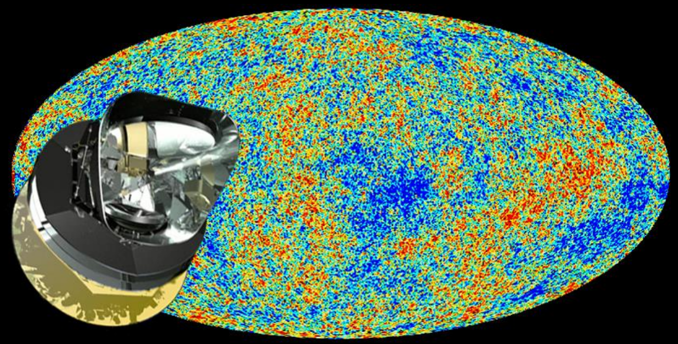
Stavros Katsanevas
APPEC Chairman, APC, Paris Diderot,IN2P3/CNRS

The oldest photo-detector
Served astronomy for ca 5000 years

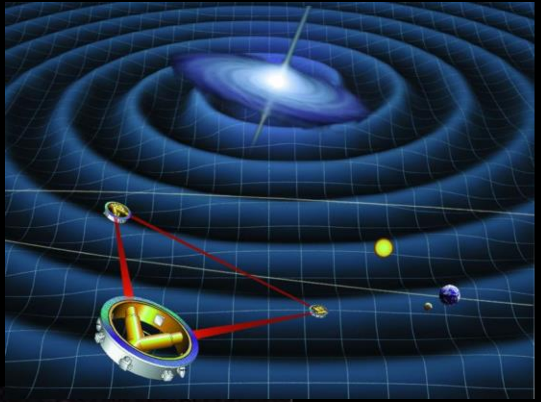


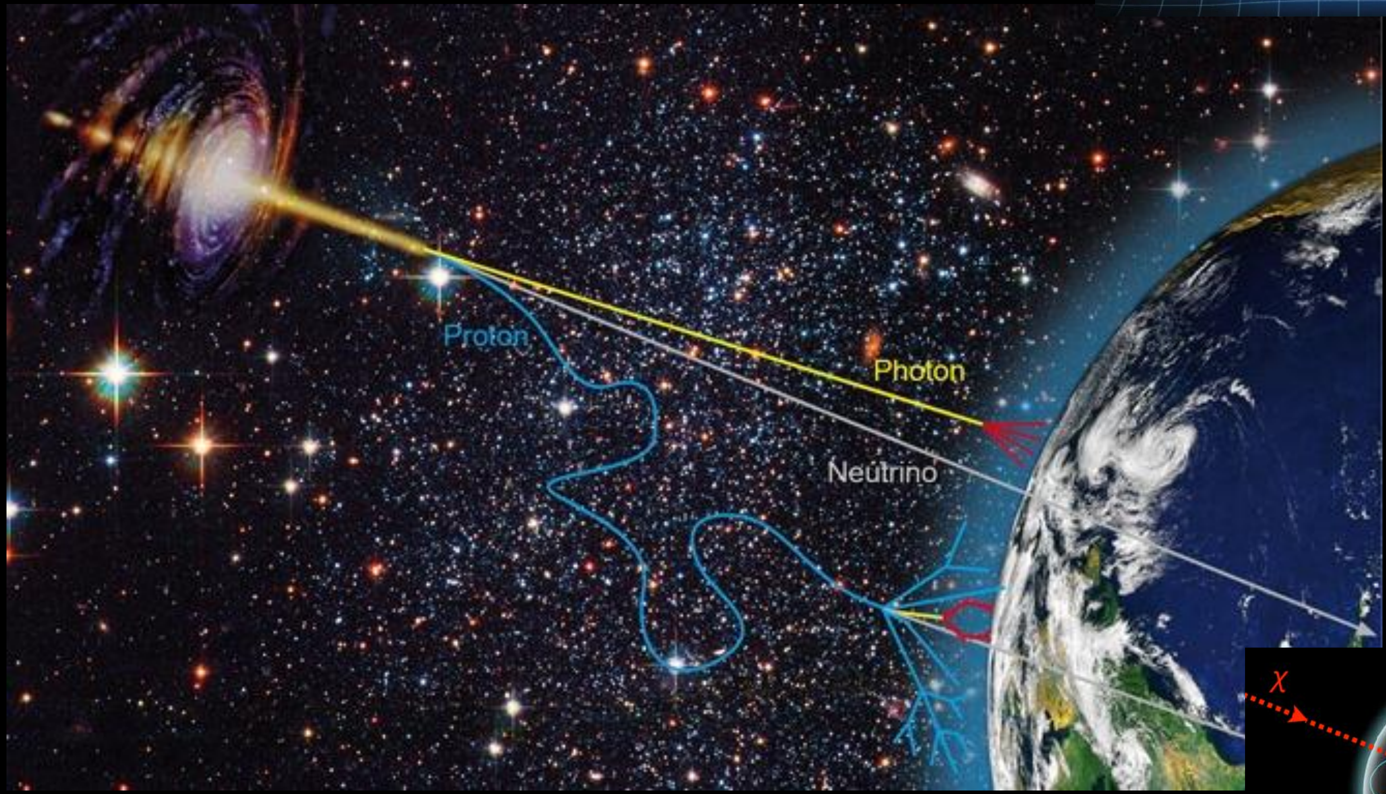
- QE ≈ 3%
- Wide band: 400-700 nm
- Dynamic range 1-10^{13}
- Angular resolution 1'
- Integration time ≥ 30 ms
- Threshold 5-7 green photons (after a few hours of adaptation in the dark)

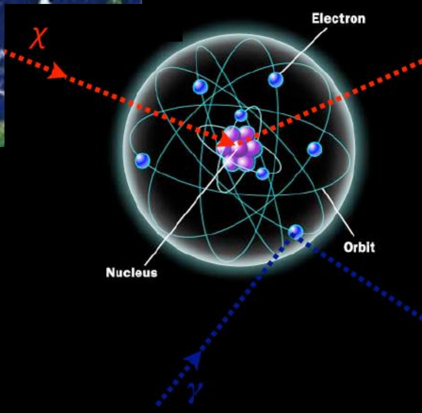
« Maybe that's what life is… a wink of the eye and winking stars » J. Kerouac



Light is not anymore the only starry messenger

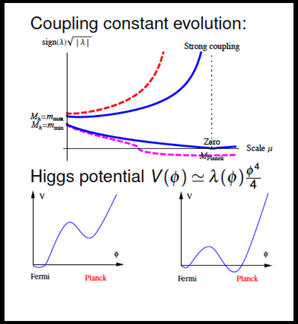






But most of the new messenger detectors use photodetection ➔ leading innovation

Astroparticle Physics is promoting the unity of fundamental physics
Going up and down the cosmic ladder



Jacob's ladder

The Astroparticle domain after LHC/PLANCK/ν results can be reduced to 2 fundamental questions:

1) Are there any intermediate scales between the EW scale and Inflation ? If yes how many and where are they ?
   - Inflation, dark energy and matter
   - Neutrino properties and proton decay

2) Are there new energy scales at work in the most violent phenomena of the Universe? How do particles and fields shape the formation and evolution of cosmic structures ?
   - High energy photons, neutrinos, CR
   - Gravitational waves

Summary of the roadmap statements of November 2011, specified in January 2013 as input to the European Strategy of Particle Physics

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I. In the category of medium scale projects: the timely completion of the 2^{nd} generation upgrades of gravitational wave antennas, as well as the upgrades/constructions towards ton-scale detectors for dark matter and double-beta neutrino mass experiments.

II. In the category of large-scale projects a high priority is given to the construction of the Cherenkov Telescope Array (CTA), and strong support for the first phase of KM3NeT, as well as R&D towards the definition of the next generation ground-based observatory for high energy cosmic rays.

III. Finally there needs to be coordination with other European/non-European organizations for the realization of billion-euro scale projects at the 2020 horizon, in particular a 50-500 kt scale low-energy neutrino astrophysics/proton-decay detector. Other projects on this cost scale are dark energy surveys on ground and in space, and in a longer perspective gravitational wave antennas with cosmological sensitivity on ground and in space.

CAUTION: THIS IS THE ROADMAP WHAT I WILL SHOW HAS A PHOTODETECTOR BIAS

Update of the Roadmap, « budget aware »
➔ end of 2014

A Photodetection classification of Astroparticle Physics experiments

I. High Energy Universe and neutrino physics
   - Classical photomultipliers to SiPM

II. Large cosmological surveys (astronomical dark matter, dark energy)
   - Giga-pixel detectors

III. Dark matter (and DBD) searches with noble liquids and bolometers
   - Low radioactivity and cryogenics

IV. Dark matter and inflation
   - Bolometers for dark matter and TES detectors
   - Bolometric matrices with TES and KIDS

I. High Energy Universe and Neutrino Physics

Many thanks to R.Mirzoyan, W. Hofmann, R. Walter, M. DeJong, E. Parizot, T. Patzak for this part

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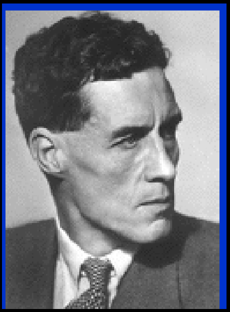
A physicist’s Stradivarius* :classic photomutiplier

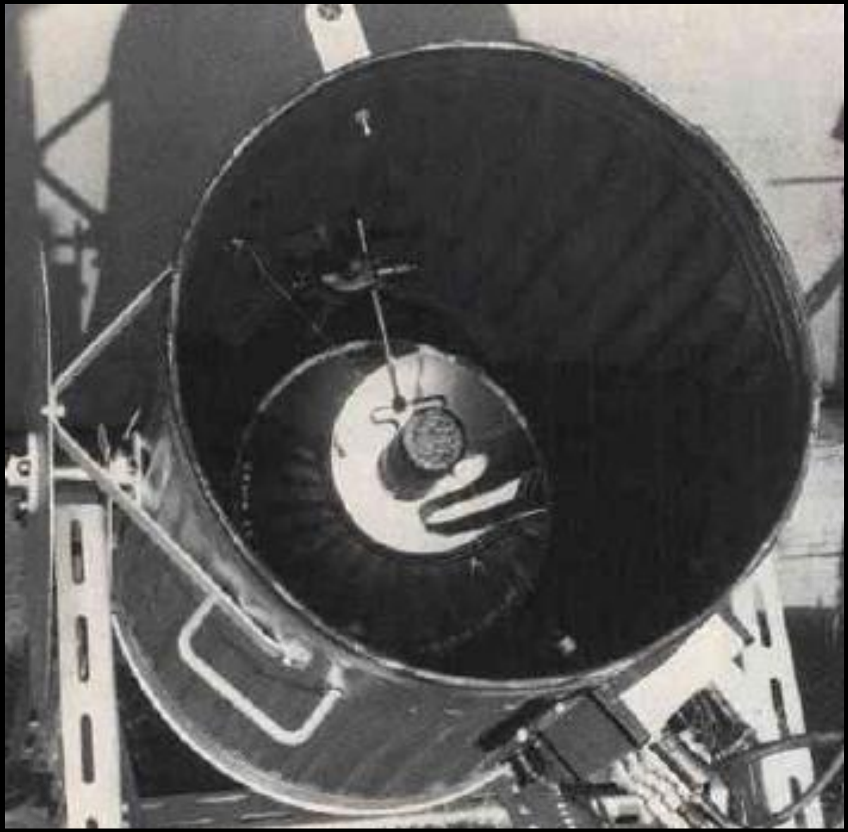
Patented in 1930 first constructed by Kubetsky in 1934 a 80 year old lady, alive and kicking well

Photoelectric effect + acceleration structure

*Stradivarius: Human labour large part of its cost (3D printing?)

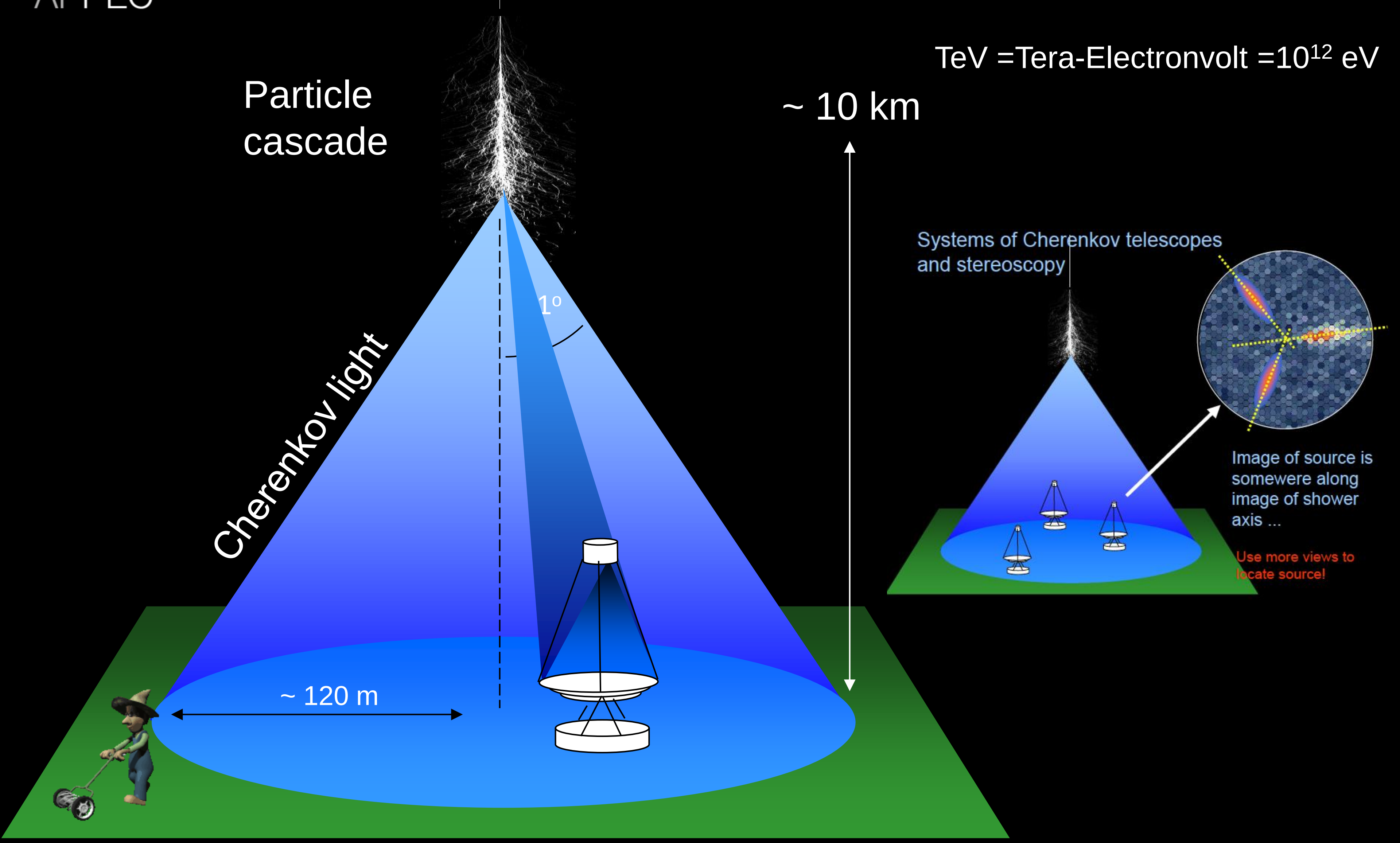


1948 Patrick Blackett was the first to mention that there shall be Cherenkov light component from relativistic particles in air showers (mostly e-, e+, μ-, μ+)



1953 By using a garbage can, a 60 cm diameter mirror in it and a PMT in its focus Galbraith and Jelly had discovered the Cherenkov light pulses from the extensive air showers.

Detection of TeV Gamma Rays
using Cherenkov telescopes



1000-2000 pixel cameras today
Exemple H.E.S.S (6000 PMT)

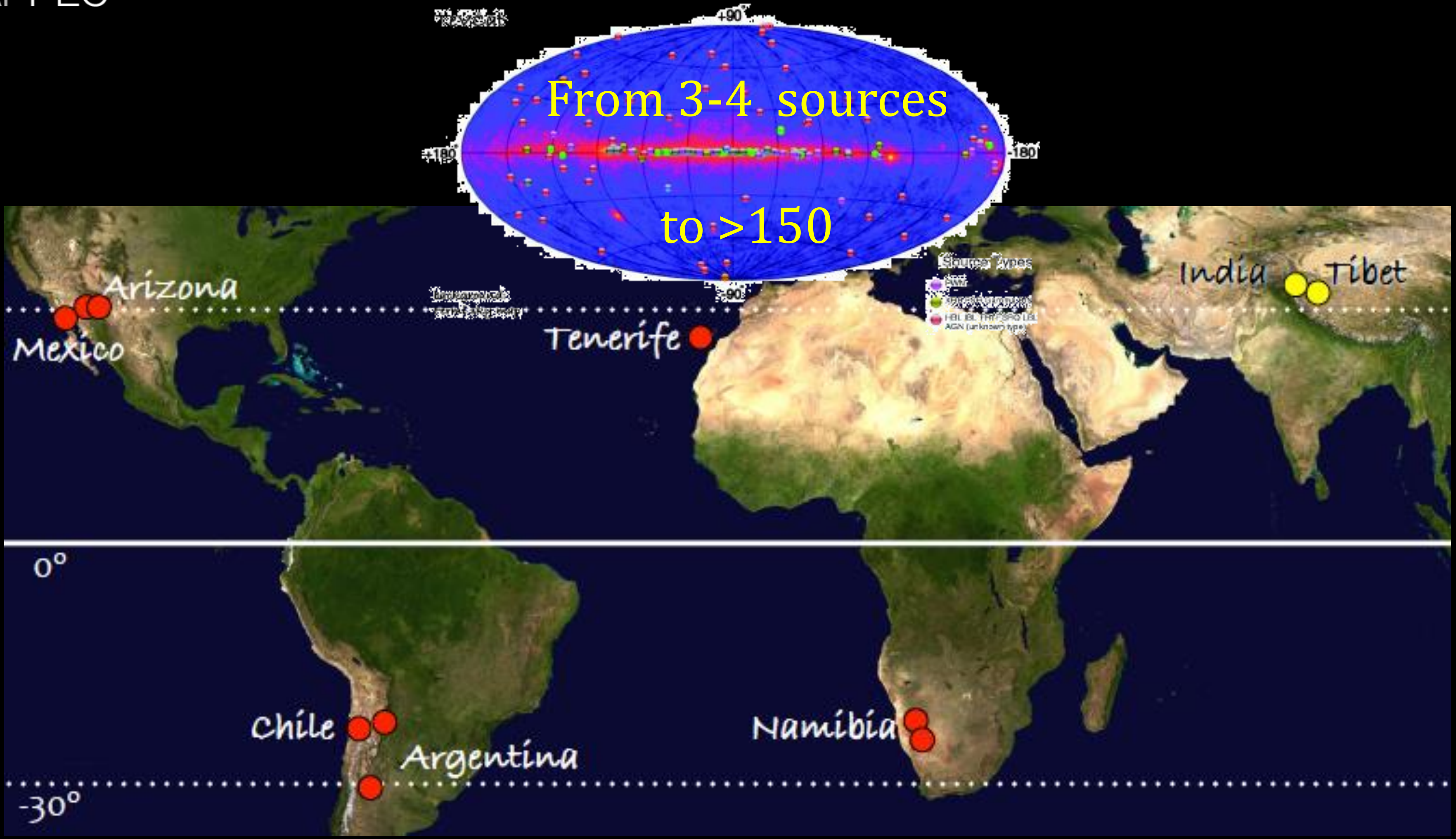
4 cameras H.E.S.S 1
800 kg, 1,5x1,6m^2, 960 PMT

1 camer afor H.E.S.S.2
3000 kg, 2,2x2,4 m^2 1920 PMT

- QE ~25-27%, CE ~85%

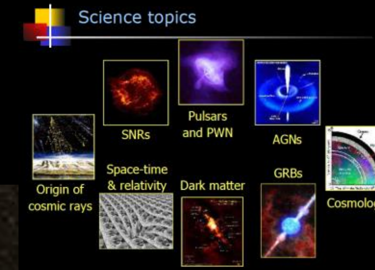
A lot of R&D in the MAGIC Community, advancing the performances of the PMTs

The era of high energy photon (TeV) astronomy has started 10 years ago (~2004)



- CTA South : Start negotiations in priority with Namibia, Chile and eventually Argentina

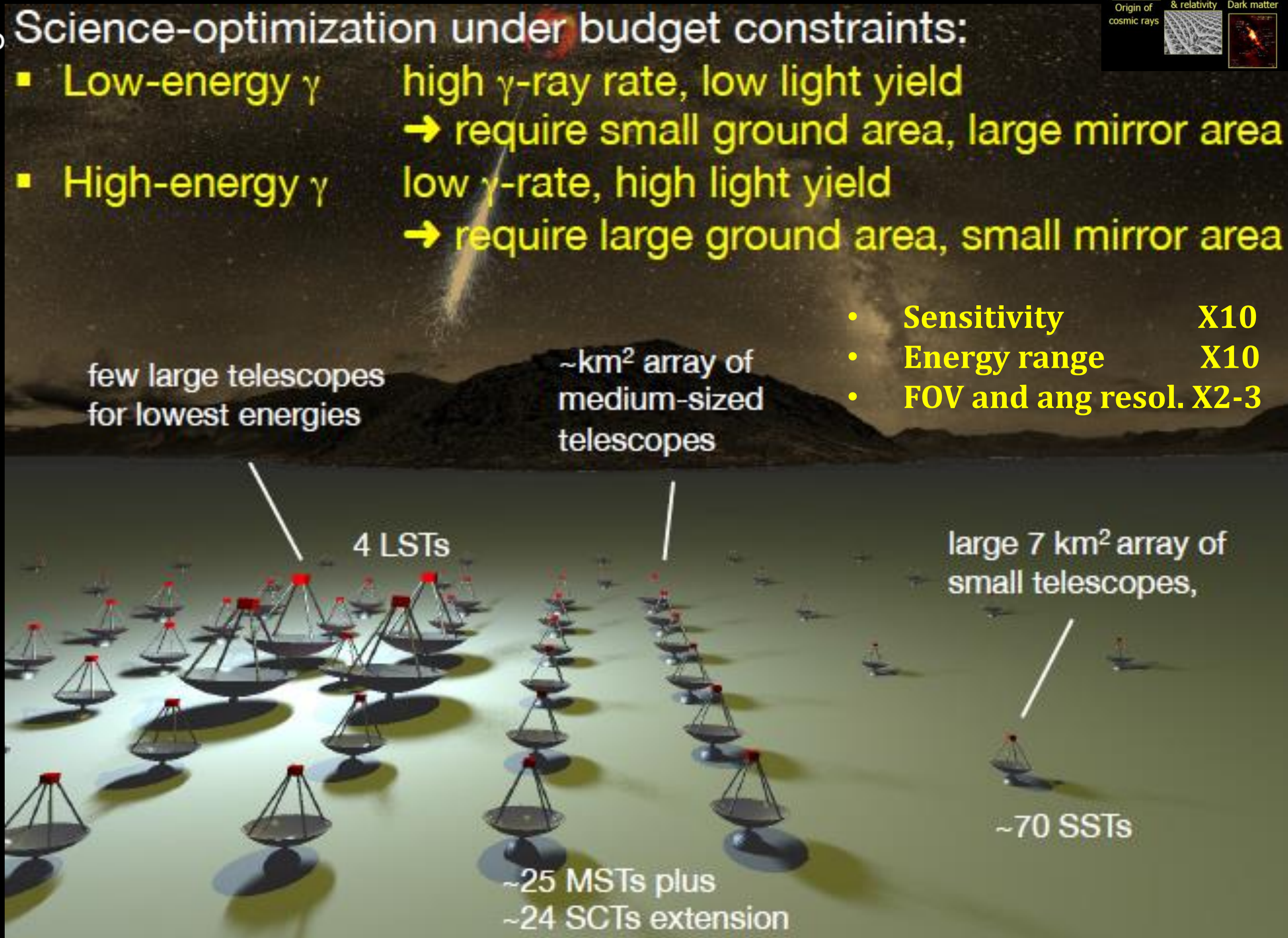
CherenkovTelescope Array   CTA



Science-optimization under budget constraints:

- Low-energy γ   high γ-ray rate, low light yield
  ➜ require small ground area, large mirror area
- High-energy γ   low γ-rate, high light yield
  ➜ require large ground area, small mirror area

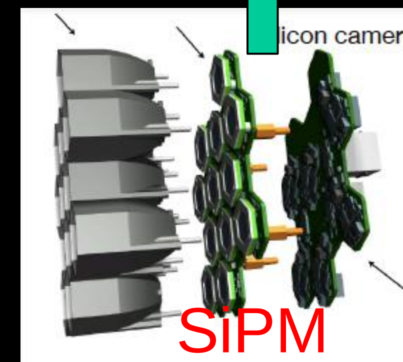
- **Sensitivity X10**
- **Energy range X10**
- **FOV and ang resol. X2-3**



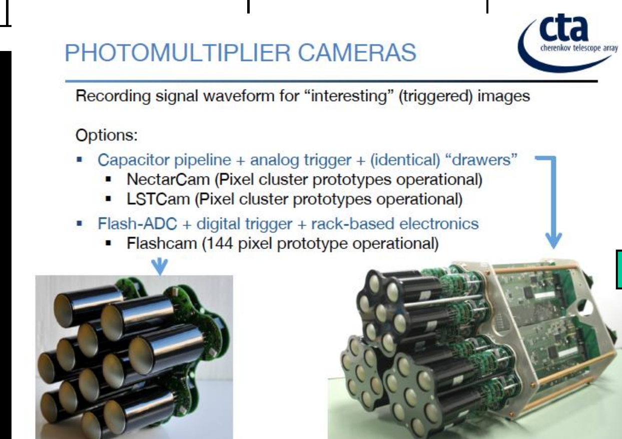
90 k PMT
100 k SiPM

+SCT(US)
272 k SiPM pix

	SST "small"	MST "medium"	LST "large"
Number	70 (S)	25 (S) 15 (N)	4 (S) 4 (N)
Spec'd range	> few TeV	200 GeV to 10 TeV	20 GeV to 1 TeV
Eff. mirror area	> 5 m^2	> 88 m^2	> 330 m^2
Field of view	> 8°	> 7°	> 4.4°
Pixel size ~PSF θ_{80}	< 0.25°	< 0.18°	< 0.11°
Positioning time	90 s, 60 s goal	90 s, 60 s goal	50 s, 20 s goal
Availability	> 97% @ 3 h/week	>97% @ 6 h/week	>95% @ 9 h/week
Target capital cost	420 k€	1.6 M€	7.4 M€



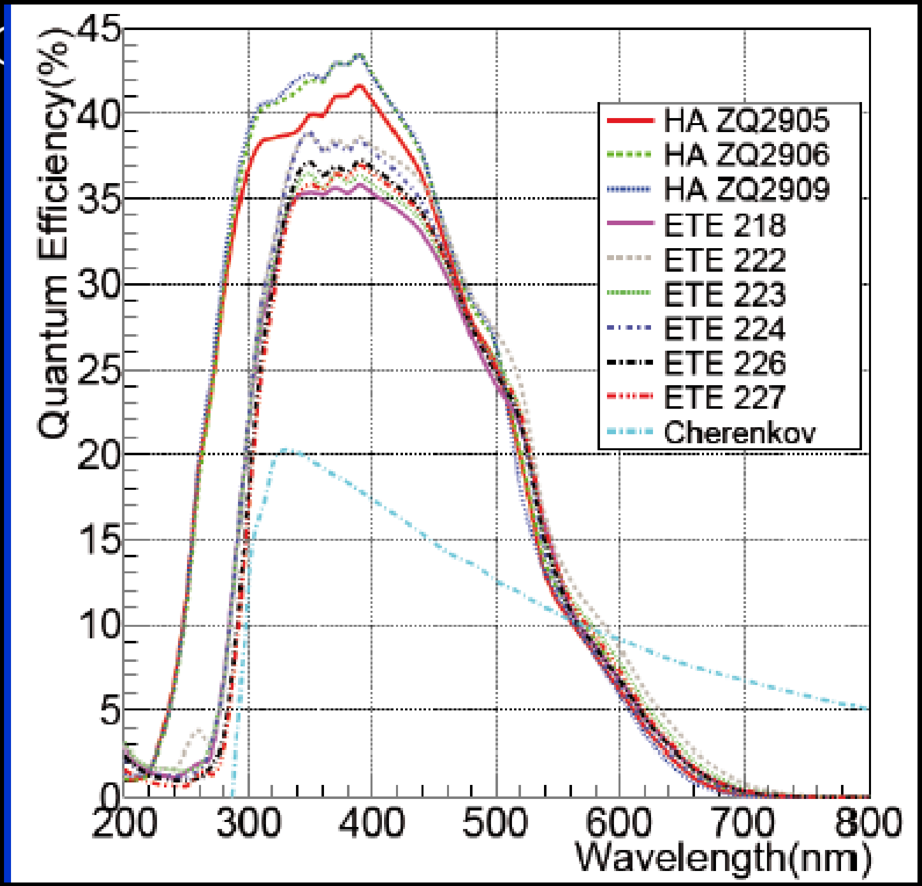
1855 pix



SiPM for LST ?
For mechanical
reasons ?

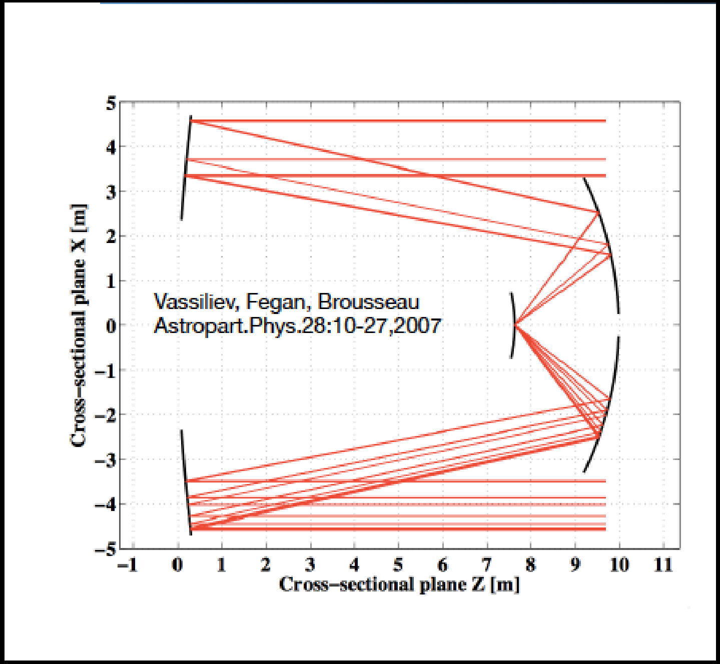
1800 pix

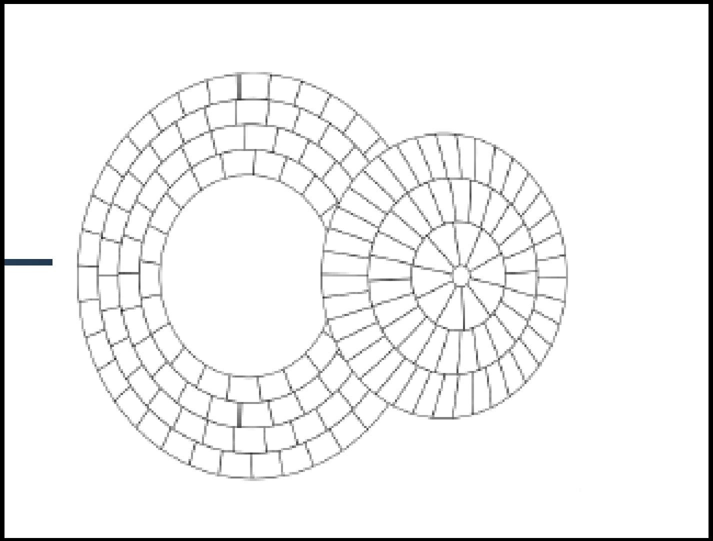
PMT candidates for CTA

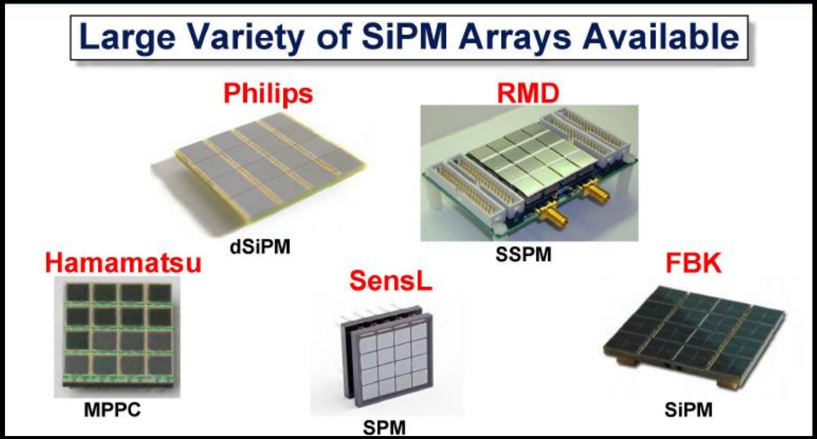


Both *Electron Tubes Enterprises* (England) and *Hamamatsu* (Japan) have made a big progress.
The average QE level moved towards 40%
The ph.e. CE moved towards 95-98%
Compared to H.E.S.S. already with these tubes one gets +60% enhancement

Dual mirror telescopes
a SiPM testing ground







- Reduced focal plane
- Reduced psf
- Uniform psf across FOV

➔ Medium-size Swarzchild-Couder telescopes (SCT)
➔ Cost-effective small telescopes with compact sensors (SST-2M)

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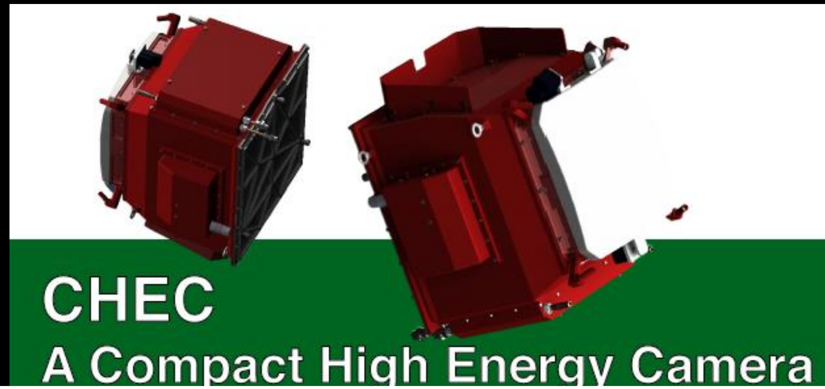
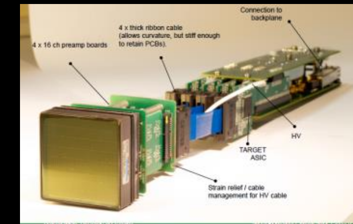
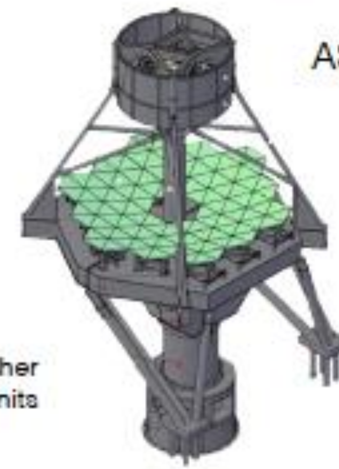




- CHEC = Compact High Energy Camera
  - Designed to equip a dual-mirror telescope
    - 4 m primary
    - 1 m radius of curvature of focal plane
  - Funding in place for 2 prototype cameras

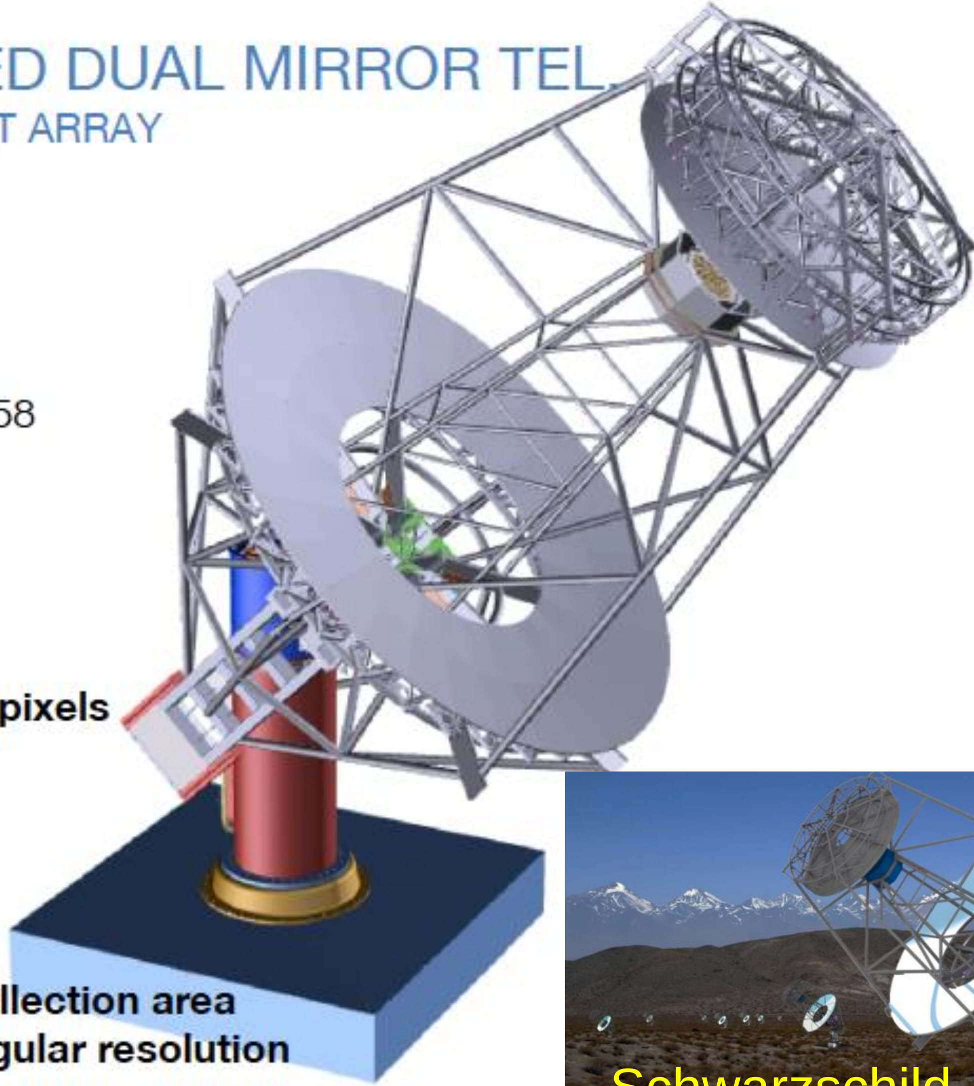
HAMAMATSU S11828-3344M

- CHEC-M:
  - Based on MAPMs
- CHEC-S:
  - Based on SiPMs



MEDIUM-SIZED DUAL MIRROR TEL.

EXTENDING THE MST ARRAY



9.7 m primary
5.4 m secondary
5.6 m focal length, f/0.58
40 m^2 eff. coll. area
PSF better than 4.5'
across 8° fov

8° field of view
11328 x 0.07° SiPMT pixels
Target readout ASIC

Extend South array by adding 24 SCTs

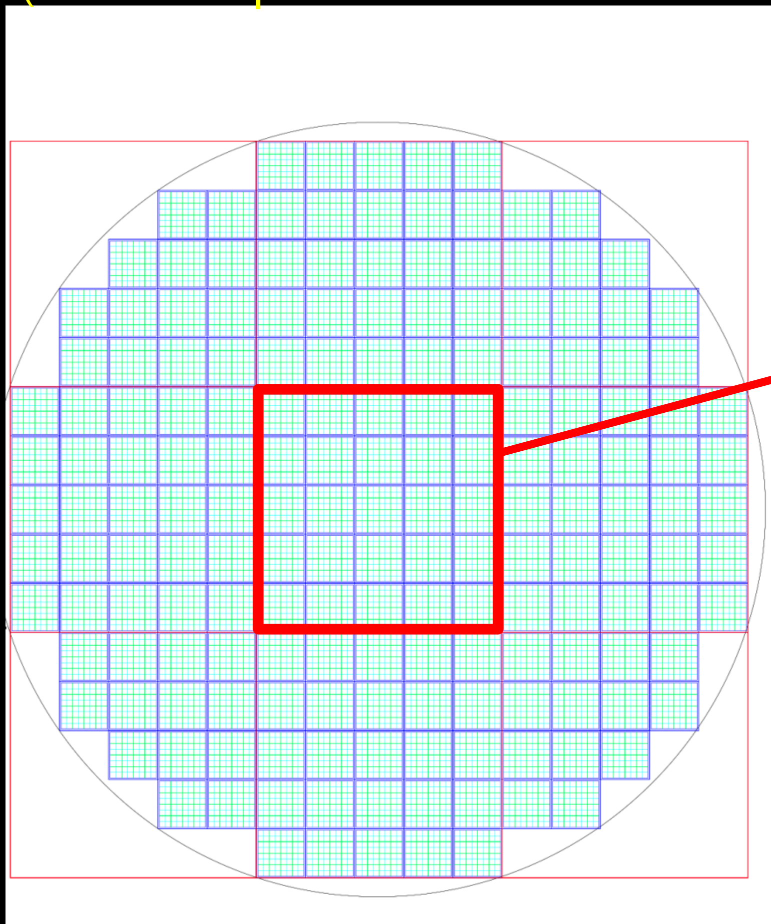
➜ increased γ-ray collection area
➜ improved γ-ray angular resolution

SCT Modular, hierarchical camera design

(1) Full camera: 9 sub-fields

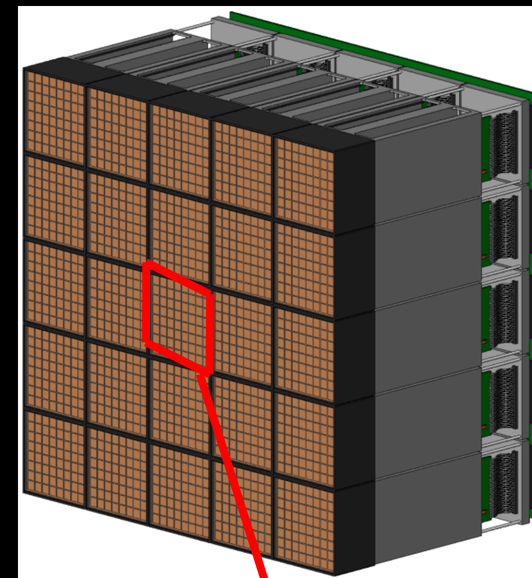
8° (0.81 m) diameter for 11,328 pixels

(24 telescopes will have 272k channels)



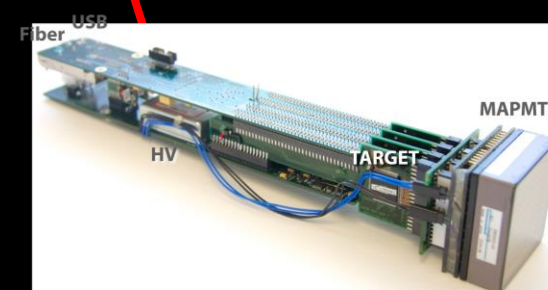
Astroparticle Physics 36 (2012) 156-165

(2) Sub-field: 25 modules



(3) Camera module:

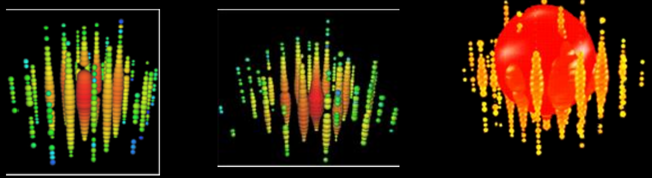
- 16 SiPM tiles
- 64 image pixels
- 16 trigger pixels
- 4 TARGET chips
- Each pixel is 0.067° (6 mm) square

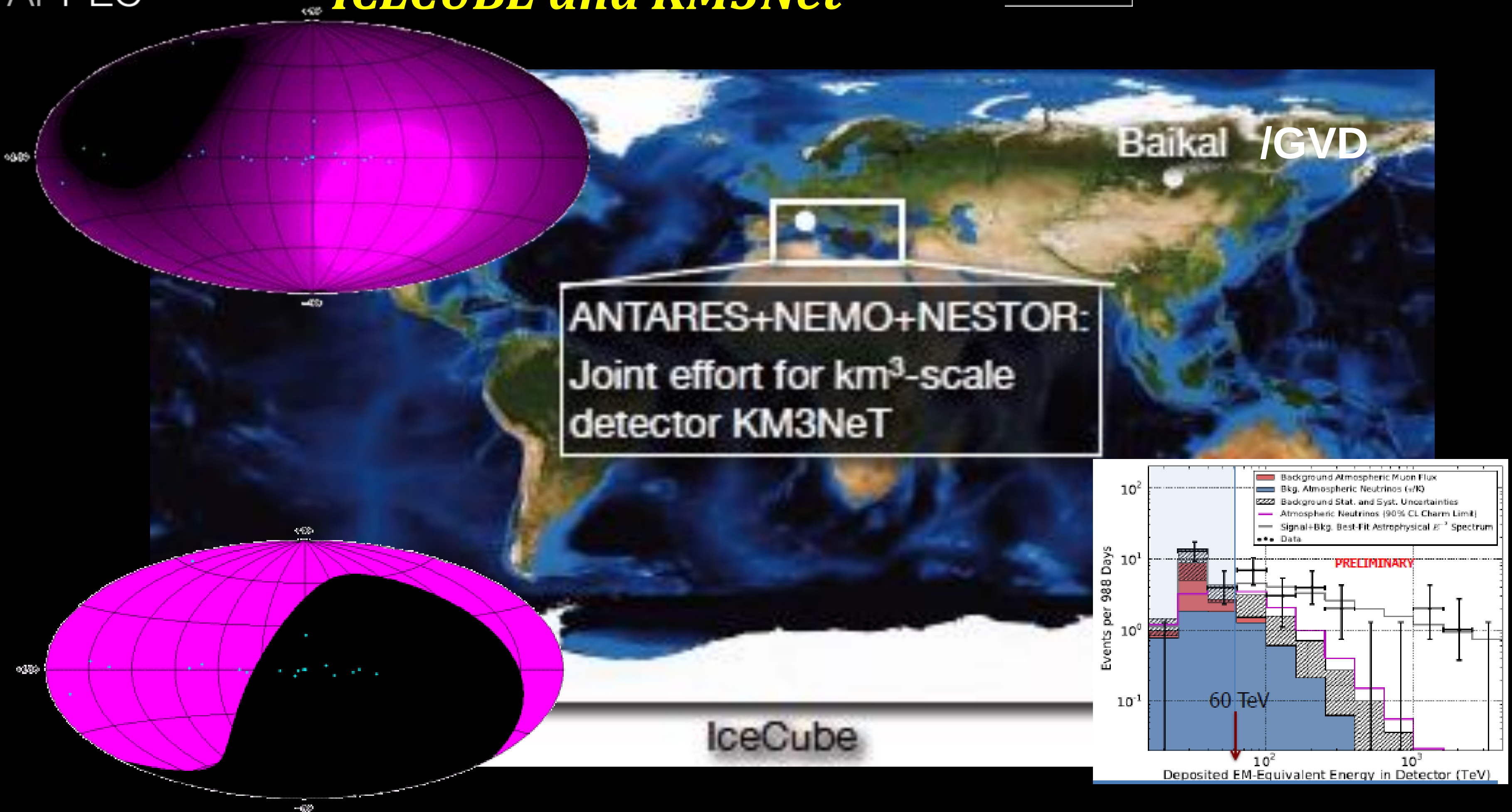


Hamamatsu S12642-0404PA-50 selected for first sub-field of prototype SCT

High Energy Neutrinos

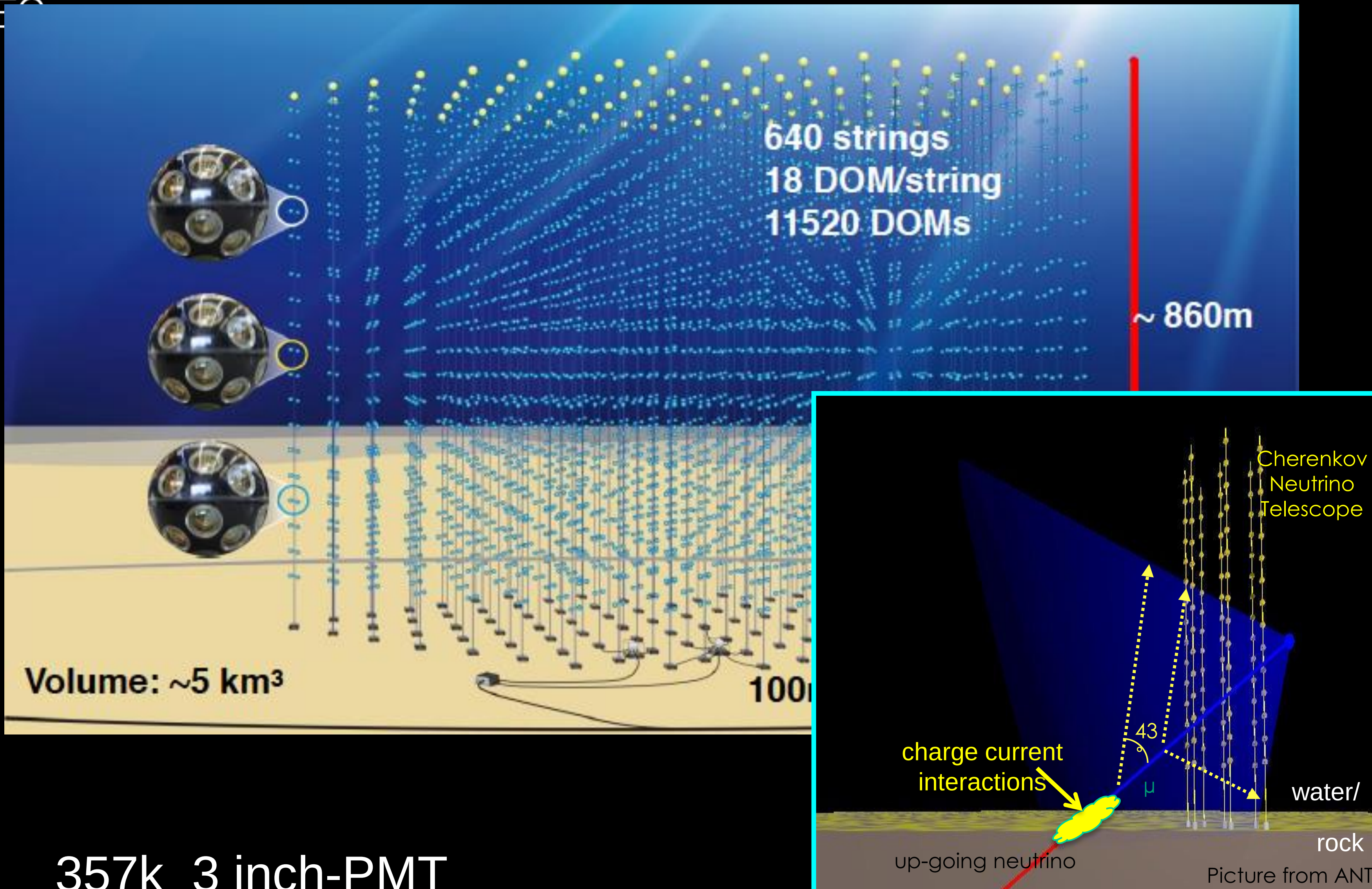
ICECUBE and KM3Net





ICECUBE events the dawn of neutrino astronomy ?

KM3Net



357k 3 inch-PMT

KM3Net Optical module

Launcher vehicle

- rapid deployment
- autonomous unfurling
- recoverable

Optical module

17”

- *31 x 3” PMTs*
- *low-power HV*
- *LED & piezo inside*
- *FPGA readout*
- *White Rabbit*
- *DWDM*

price/cm^2 ≤ 10” PMT

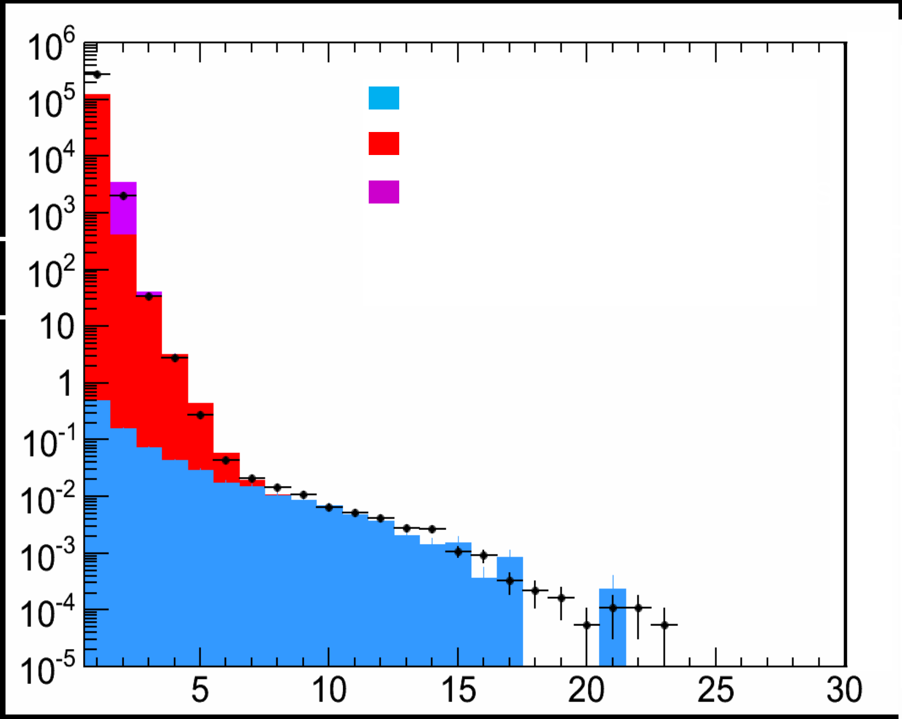
ETEL D792

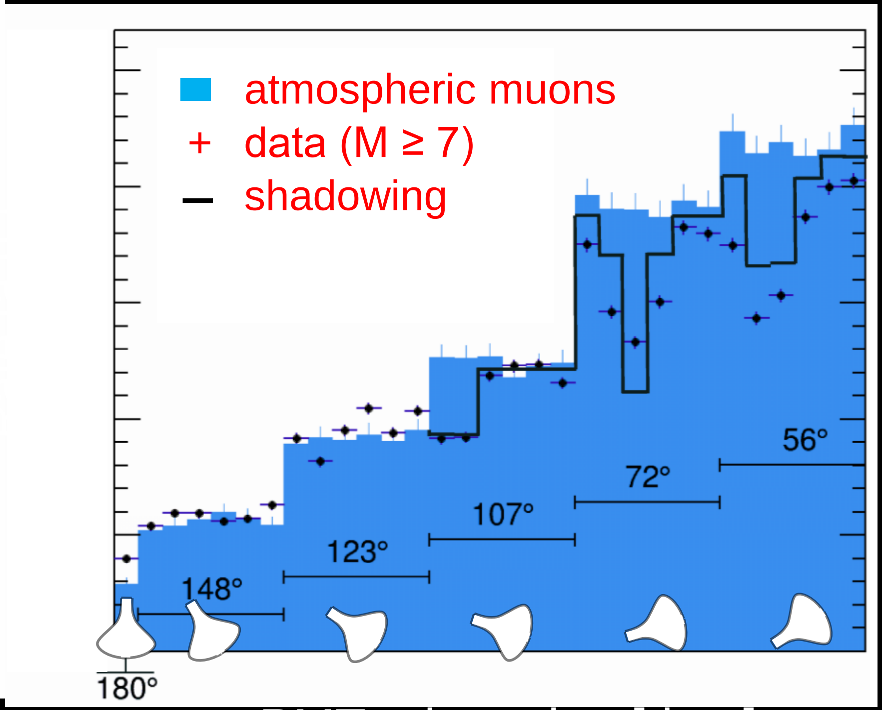
Hamamatsu R12199

HZC XP53B20

~ 600 m

Pixelisation: a game changer





✓ photon counting

✓ directionality

¶ http://arxiv.org/abs/1405.0839

KM3NET: Synchronisation, through internet (protocol IEEE1588) ➔ White Rabbit

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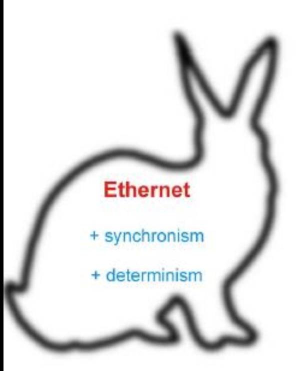

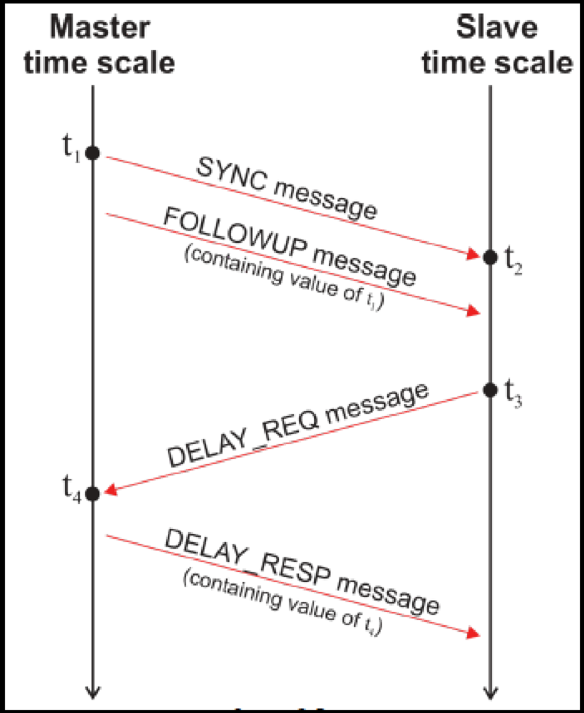

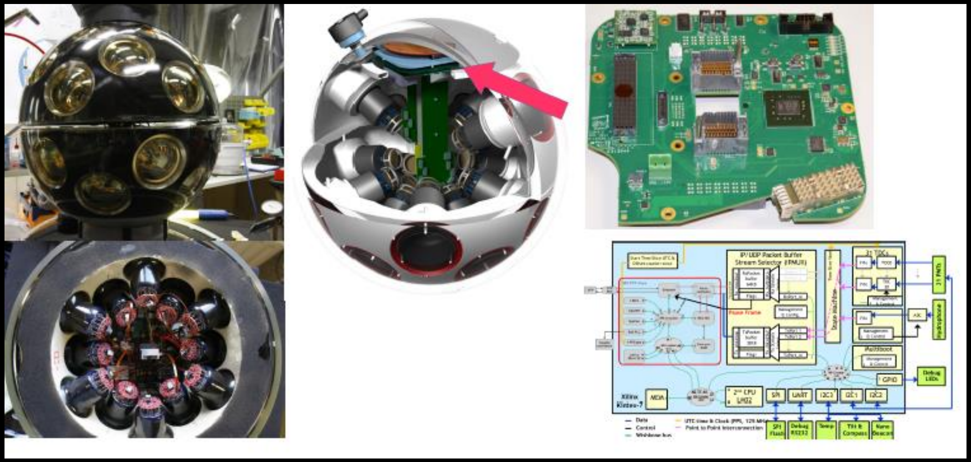

$$\text{link } delay_{ms}: \delta_{ms} = \frac{(t_4 - t_1) - (t_3 - t_2)}{2}$$

$$\text{clock } offset_{ms} = t_2 - t_1 + \delta_{ms}$$

- Already used in LNGS-CERN synchronisation
- In CTA is also one of the 2 solutions proposed .
  - The other is MUTIN
- SKA is planning to use it
- Sub-nanosecond accuracy
- Tested to 10 km and 2000 nodes
- Enables many km2 distributed "cameras"
- Many industrial applications

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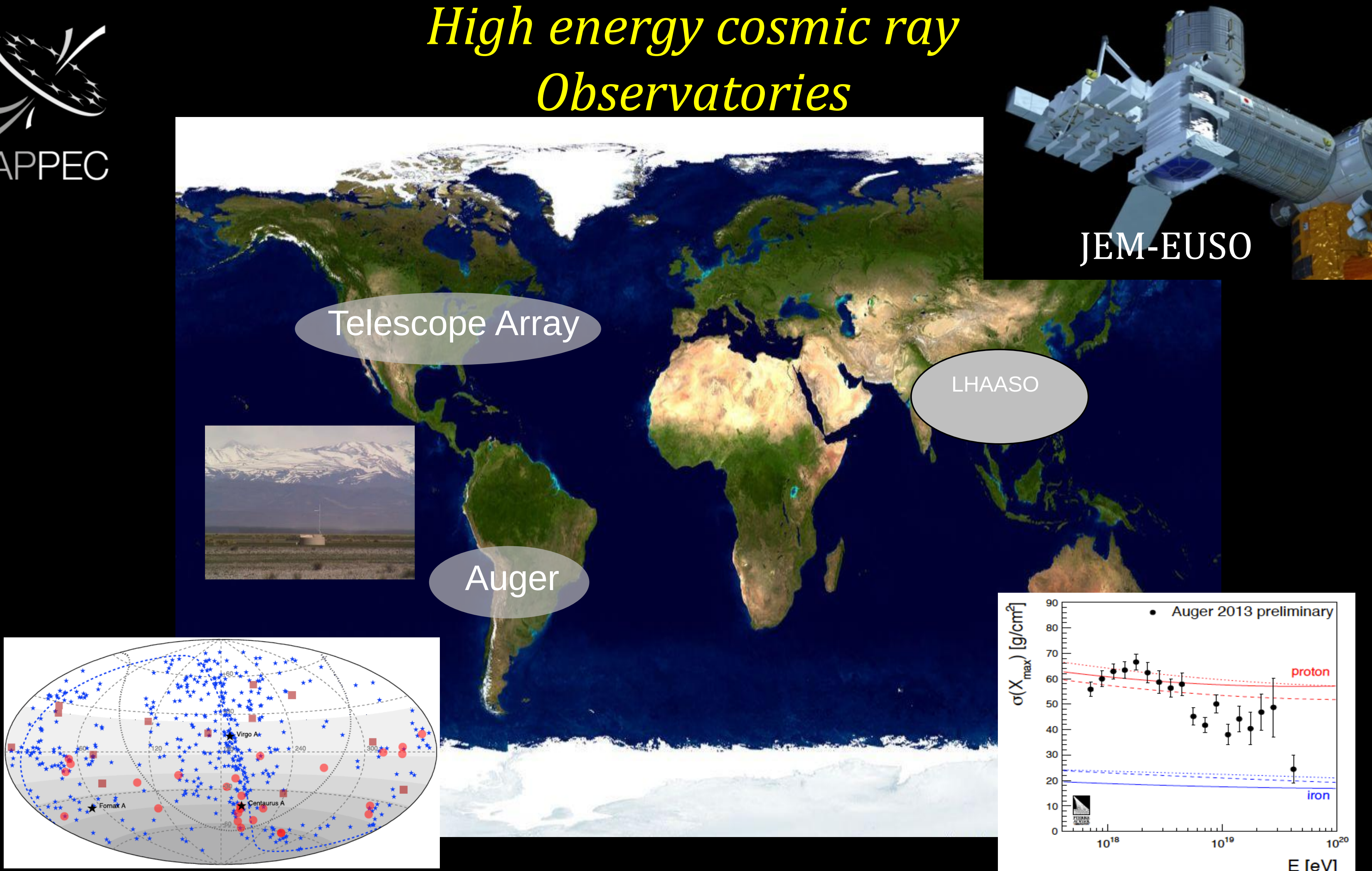
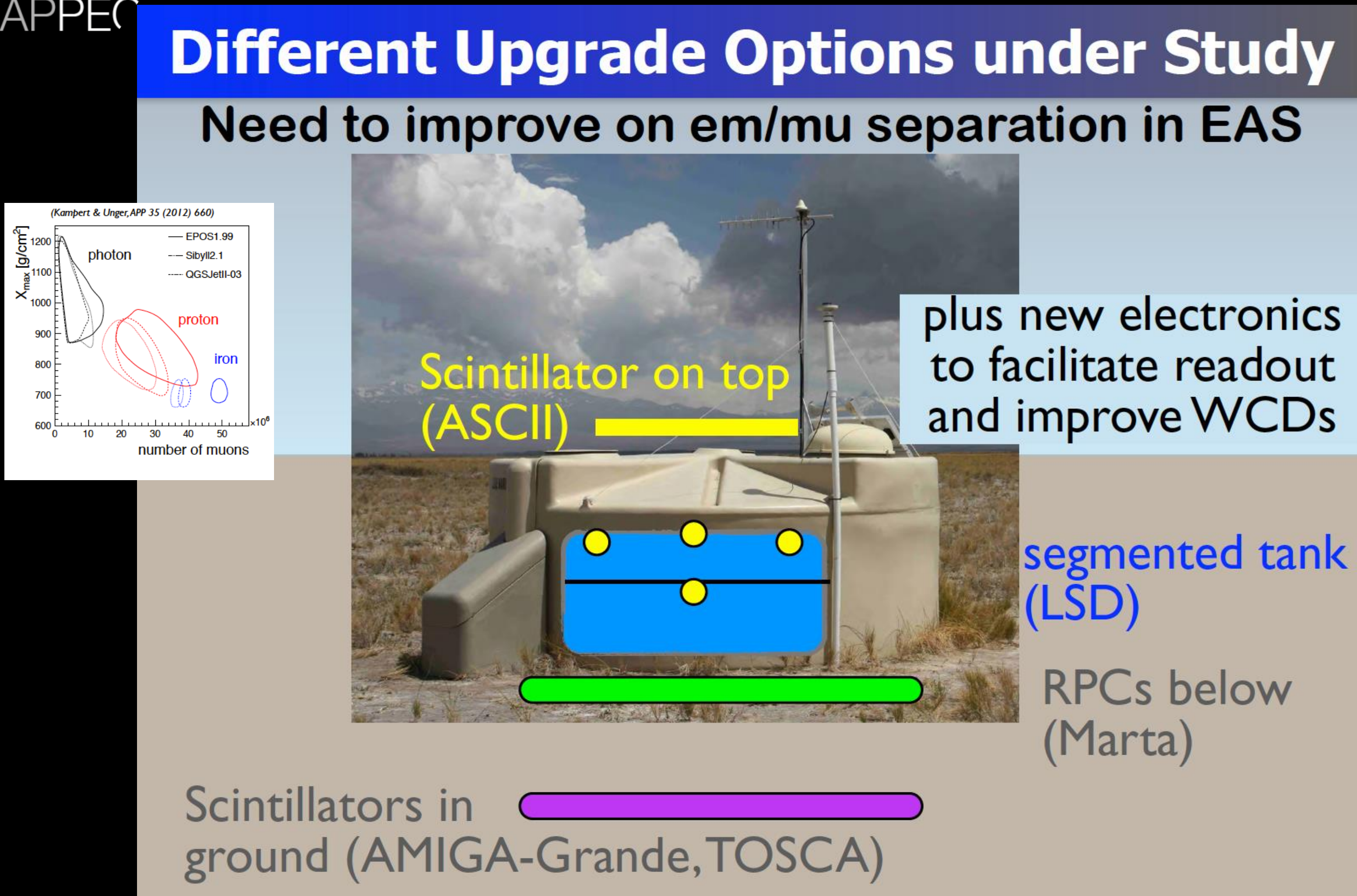
High energy cosmic ray Observatories



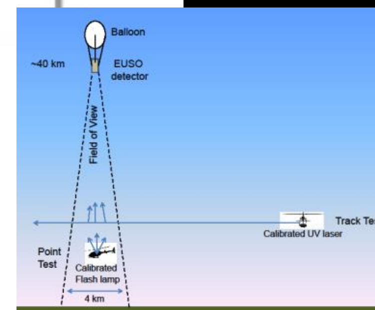
- Need to separate protons from iron in order to make astronomy
- Indications for large fraction of iron. How does one discriminate ?

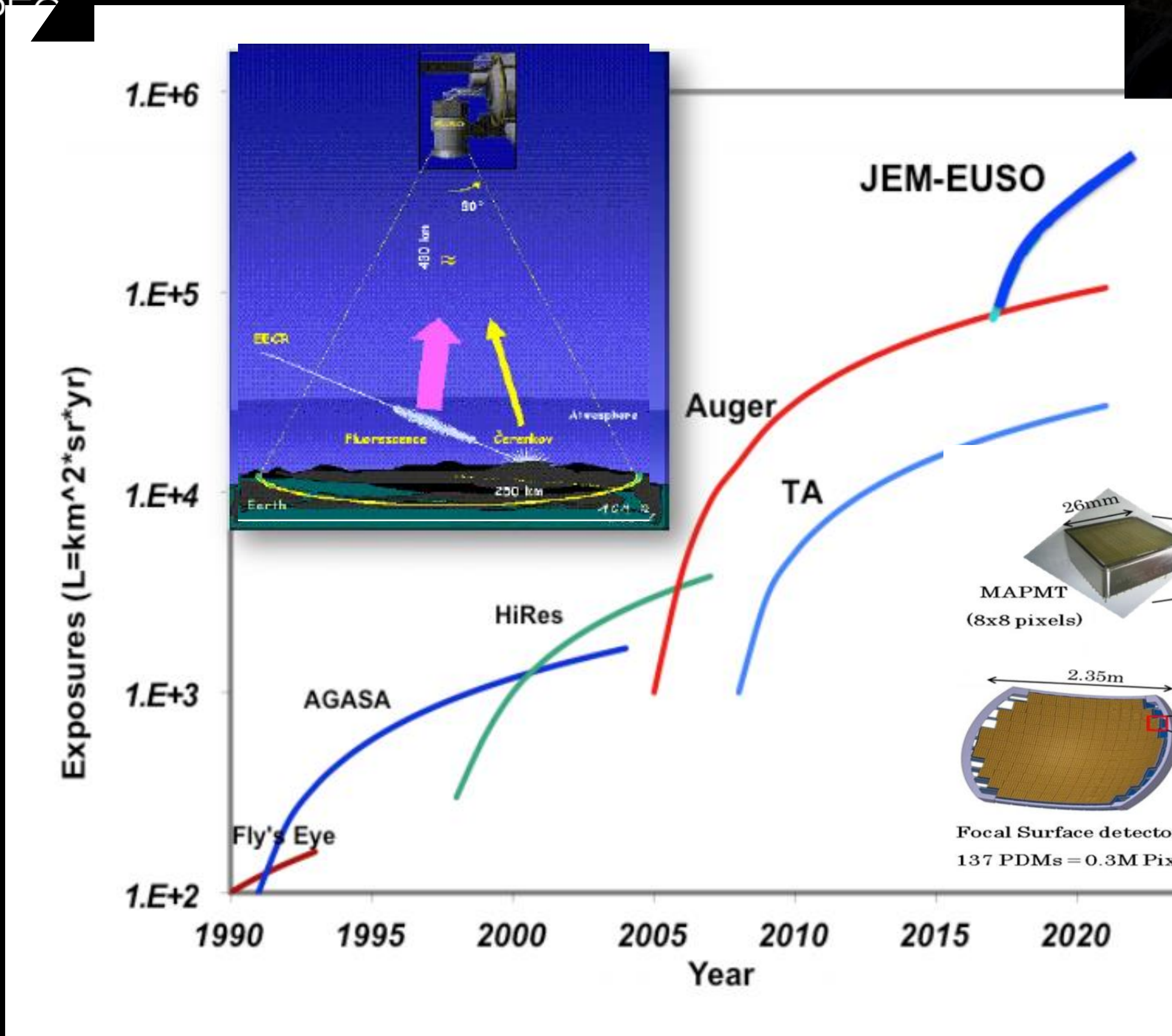
Auger upgrade

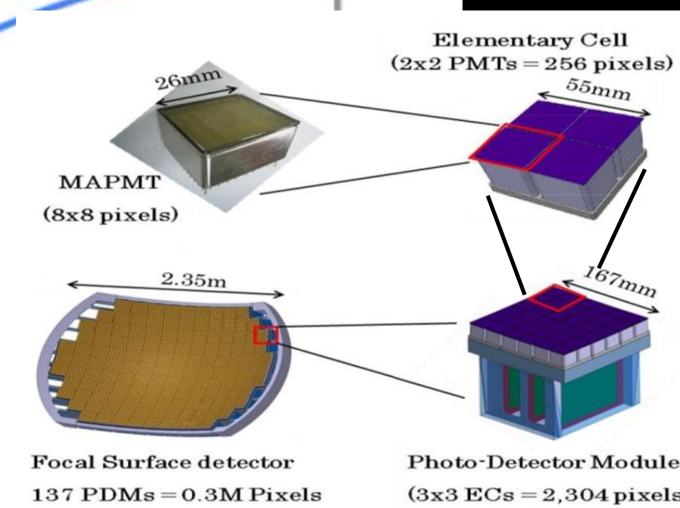


Auger collaboration prepares a medium upgrade proposal to be evaluated by an international STAC in Spring 2015

Auger in space → EUSO
300 k pixels (MaPMT)







+SPACIROC

Large underground detectors
for proton decay, neutrino physics and astrophysics

- Mass hierarchy
- θ_{23} octant
- CP-violating phase δ
- Proton decay
- Supernova
- Solar and
- Geo neutrinos

Also ESSnu, RENO, ...

Recent big step: APPEC organised International meeting for Large Neutrino Infrastructures in Paris 23-24 June: involving world-wide agency responsibles to encourage of global convergence

→ Important Press release 7th -8th of July 2014

HyperKamiokande

Hyper-Kamiokande Detector

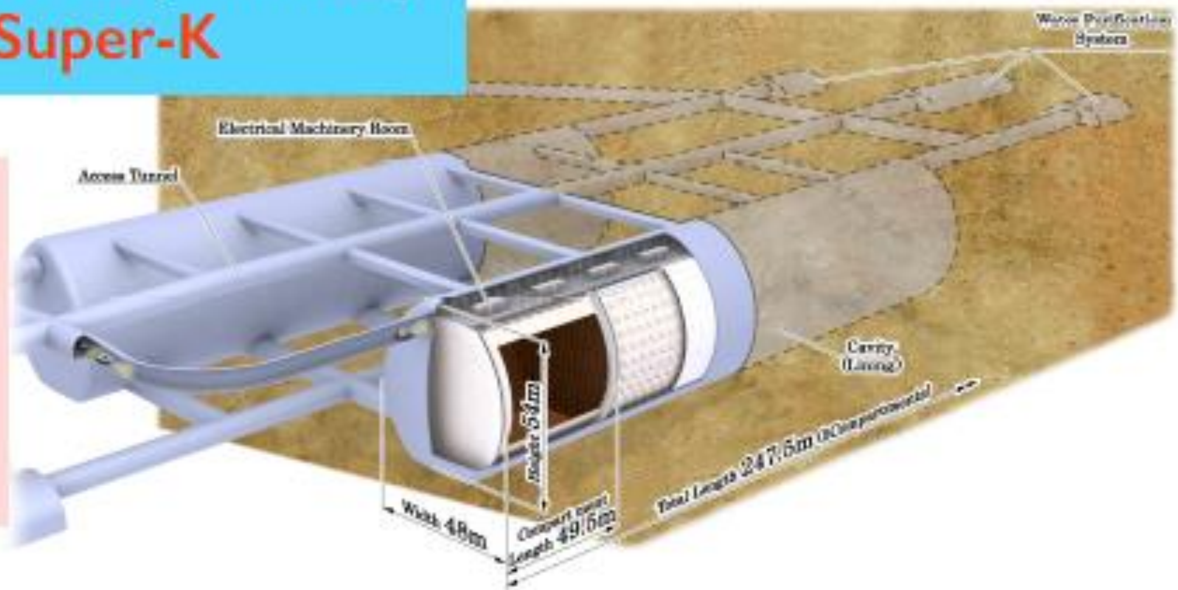
Total volume:	0.99 Mton
Inner volume:	0.74 Mton
Outer volume:	0.2 Mton
Fiducial volume:	0.56 Mton

(0.056Mton × 10 compartments)

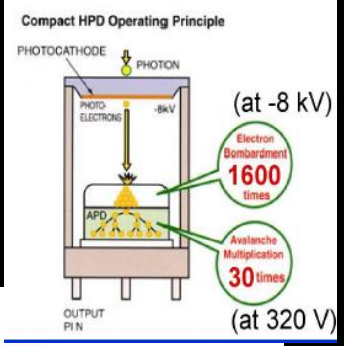
x25 of Super-K

Hyper-K WG,
arXiv:1109.3262 [hep-ex]
arXiv:1309.0184 [hep-ex]

- 99,000 20" PMT for inner-det. (20% coverage)
- 25,000 8" PMT for outer-det.



HyperKamiokande



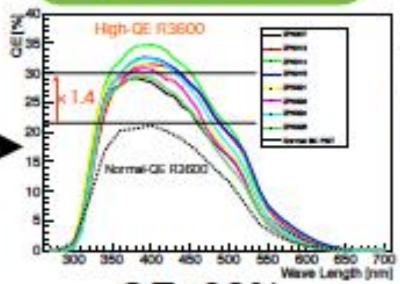
Flowchart

Super-K PMT

QE~22%

well-known

High-QE SK PMT



QE~30%

8" Hybrid Photo-Detector (HPD)

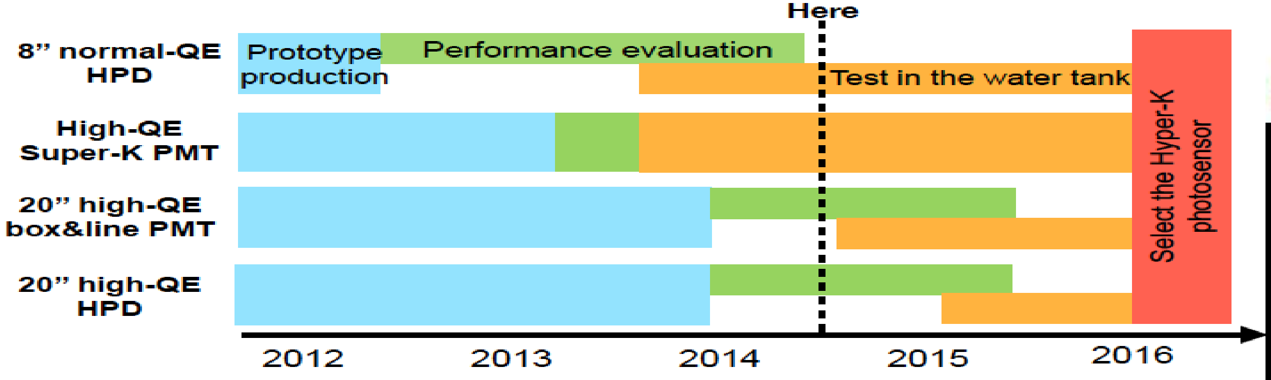
20"high-QE box&line PMT

20"high-QE HPD

Test

200-ton tank

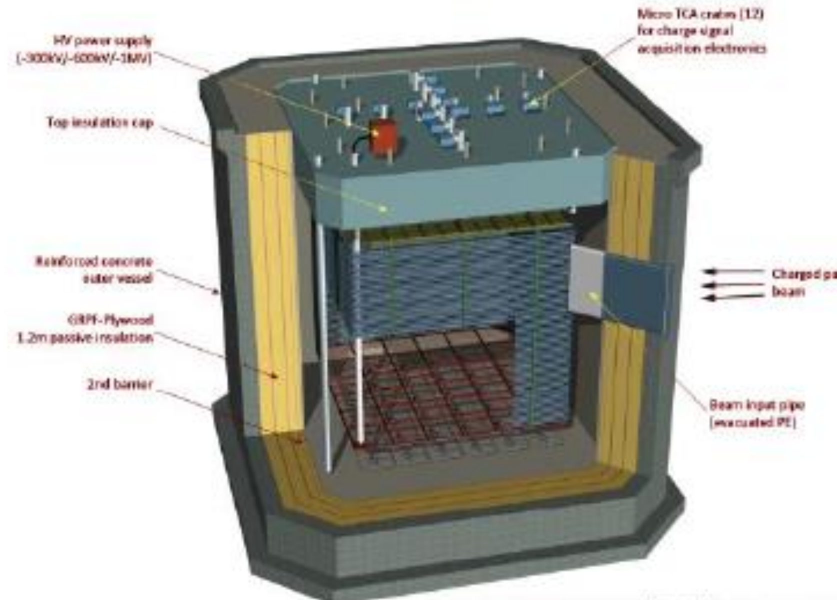
- As a first step, we developed 8" HPD and 20" high-QE Super-K PMT
- Photosensor test in a 200-ton water tank to confirm the usability of new photosensors is ongoing



Liquid argon TPCs LBNO/LBNE

DLAr 6x6x6m^3 design

- Membrane GTT® tank with passive insulation
- Top deck with chimneys and insulation
- **6x6m^2 anode large readout area, 6m long drift length** (3ms max drift time @ 1kV/cm)
- Charged particle beam window
- 300 ton LAr instrumented: 7680 charge readout channels, 36 PMTs (baseline layout)

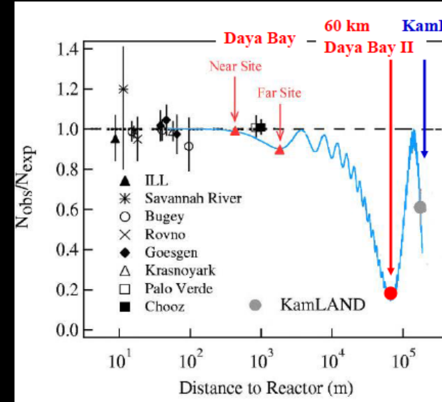


Liquid argon density	T/m^3	1.38
Liquid argon volume height	m	7.6
Active liquid argon height	m	5.99
Hydrostatic pressure at the bottom	bar	1.03
Inner vessel size (WxLxH)	m^3	8.3 × 8.3 × 8.1
Inner vessel base surface	m^2	67.6
Total liquid argon volume	m^3	509.6
Total liquid argon mass	t	705
Active LAr area	m^2	36
Charge readout module (0.5 x0.5 m^2)		36
N of signal feedthrough		12
N of readout channels		7680
N of PMT		36

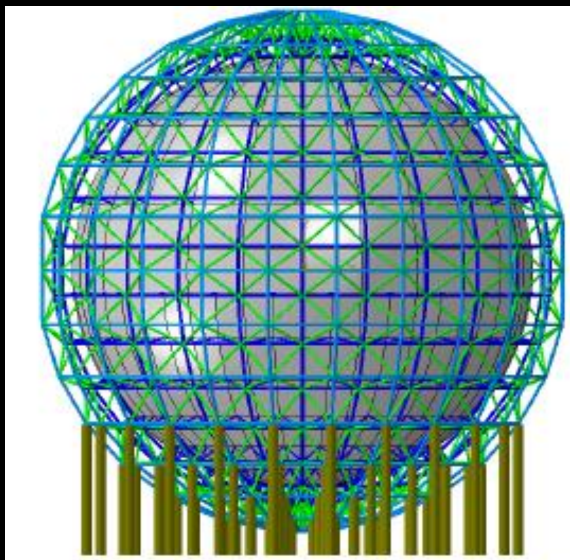
Photodetectors central but not the main detection element.
Need Cold electronics immersed in LiqAr.
Accessibility requirements close to space applications

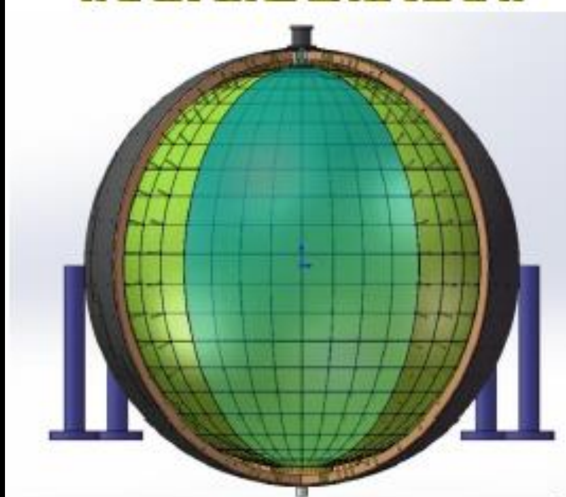
Juno

> 15000 high QE 20 inch PMT

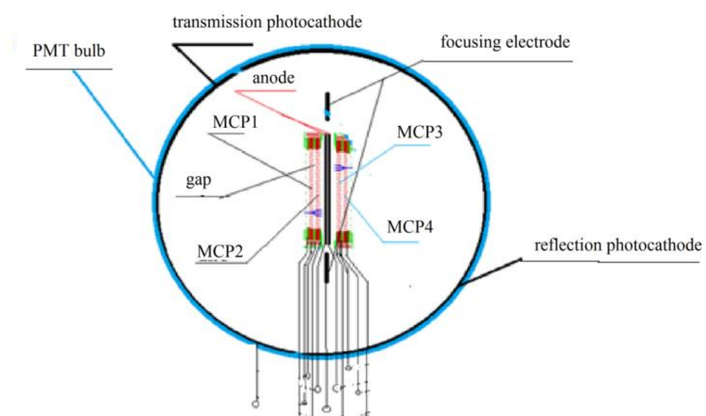


- 20 kton LS detector
- 3% energy resolution
- Rich physics possibilities
  - Mass hierarchy
  - Precision measurement of 4 mixing parameters
  - Supernovae neutrinos
  - Geoneutrinos
  - Sterile neutrinos
  - Atmospheric neutrinos
  - Exotic searches

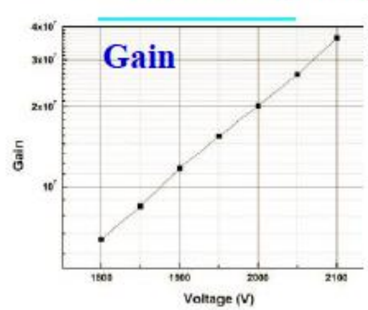


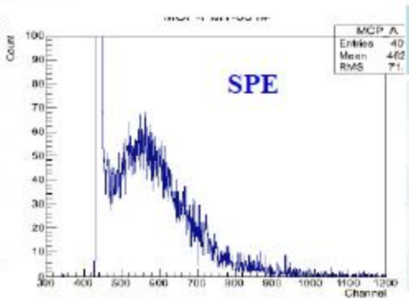


- **Three types of high QE 20" PMTs under development:**
  - New MCP-PMT: 4π collection
  - Hammamatzu R5912-100 with SBA photocathode
  - Photonics-type PMT
- **MCP-PMT by Chinese industry:**
  - Technical issues mostly resolved
  - Successful 8" prototypes
  - A few 20" prototypes



MCP-PMT





	R5912	R5912 -100	MCP-PMT
QE@410nm	25%	>30%	25-30%
Rise time	3 ns	3.4ns	5ns
SPE Amp.	17mV	18mV	17mV
P/V of SPE	>2.5	>2.5	~ 2
TTS	5.5ns	1.5 ns	3.5 ns

Large High Energy cosmic ray and neutrino cameras

Let us recapitulate:

- Neutrino property experiments need 120k 20-inch PMTs
- KM3Net needs 350k 3-inch PMTs
- CTA needs 100k 1.5-inch PMTs
- CTA needs also 100k SiPM pixels (or G-APD or MAPMT channels)
- CTA-CST needs 300k SiPM pixels
- JEM_EUSO needs 300k MAPMT channels

They are accompanied with special electronics (e.g SPACIROC, TARGET, …), integrated systems (flashcam, nectarcam,…) and white rabbit synchronisation. They can be considered as « distributed » cameras of 100 to 300 kpixels…

The classical PMTs continue to improve

SiPM, MAMPT, G-APD made (make) their way to large implementations

Procurement Issues (close to 1/3 of the cost of the program)

- Is the industrial capacity enough ?
- Is there enough diversity of procurement ?

I. Dark energy and astronomical dark matter surveys

➔ Enterig the Giga-pixel era (LSST)

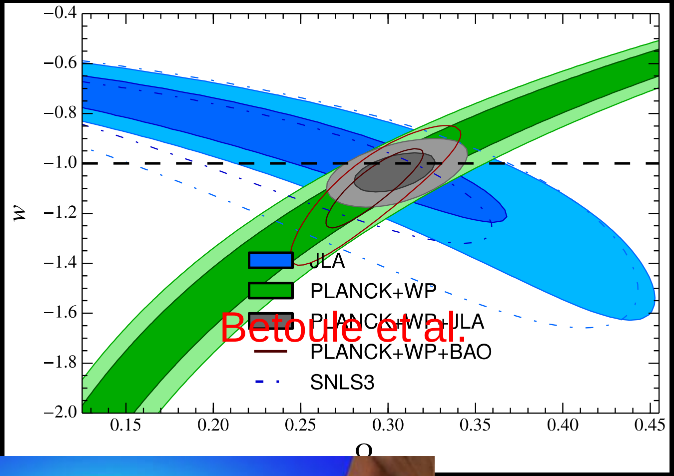
➔ Extending to NIR (EUCLID)

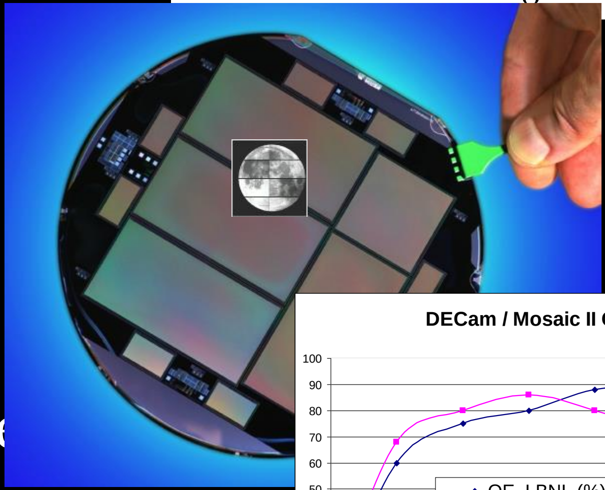
Many thanks P. Antilogus and R. Barbier for this part

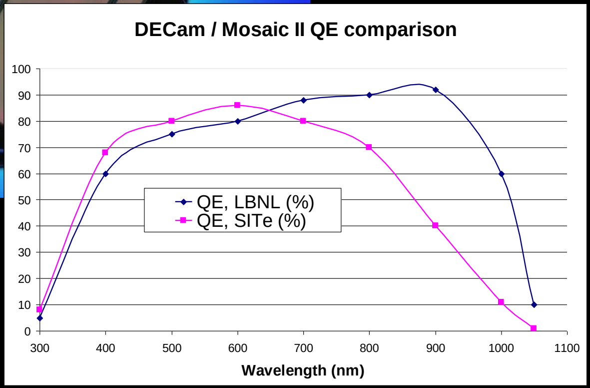
APPEC

Ca 2000 the era of large surveys started (astronomical dark matter and dark energy)

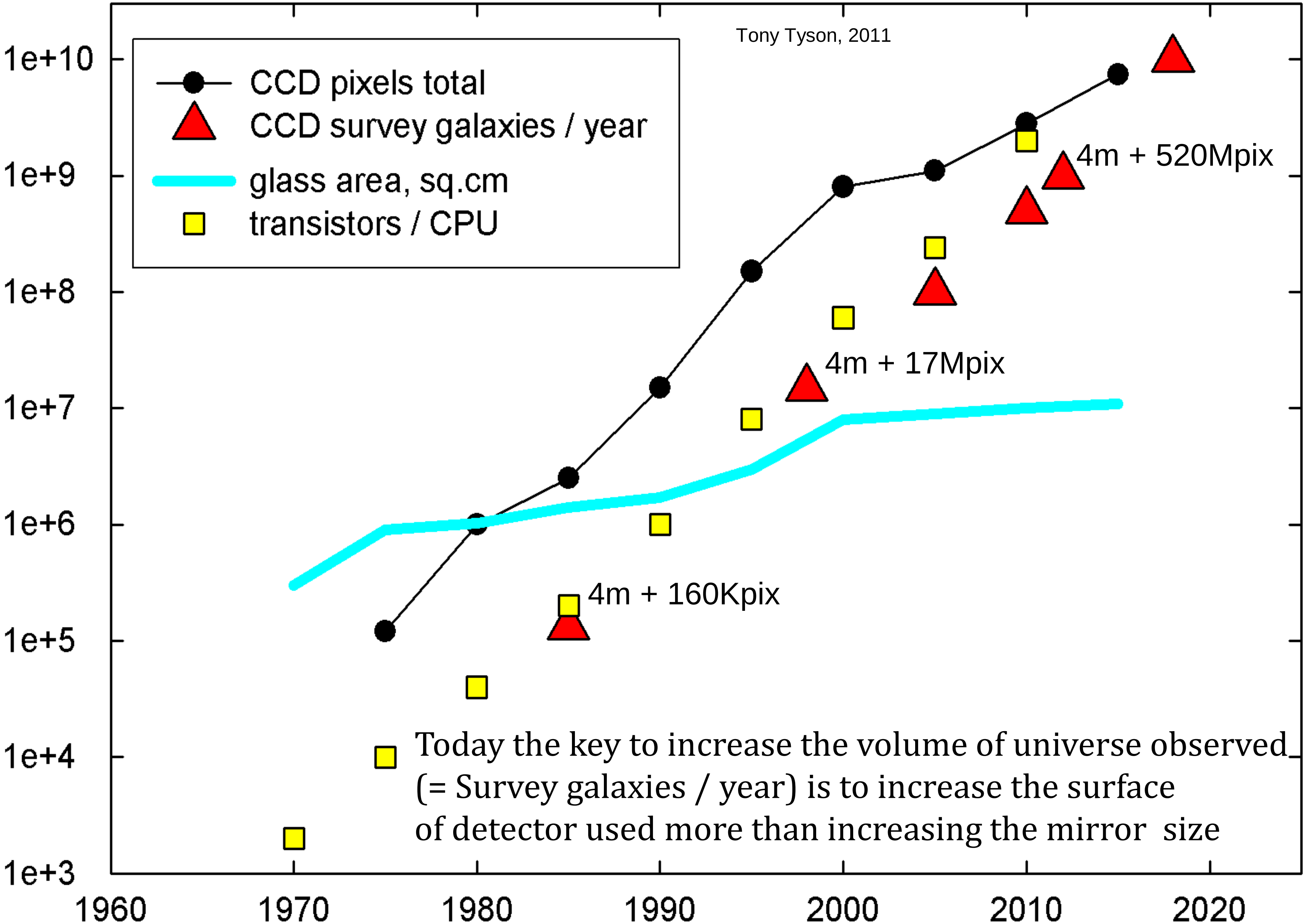
- SNLS has been a key element in the determination of dark energy parameters. It used:
  - MEGACAM 340 Megapixels,
  - 36 CCDs 2Kx4,6K
- Currently DES is using
  - DECam 520 Megapixels,
  - 62 CCDs 2Kx4K
  - 15 micron (0.264”) pixel siz



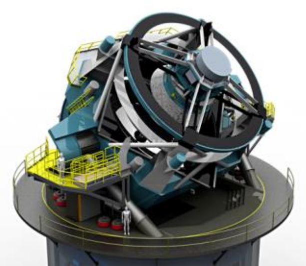




Trends in Optical Astromomy Survey Data



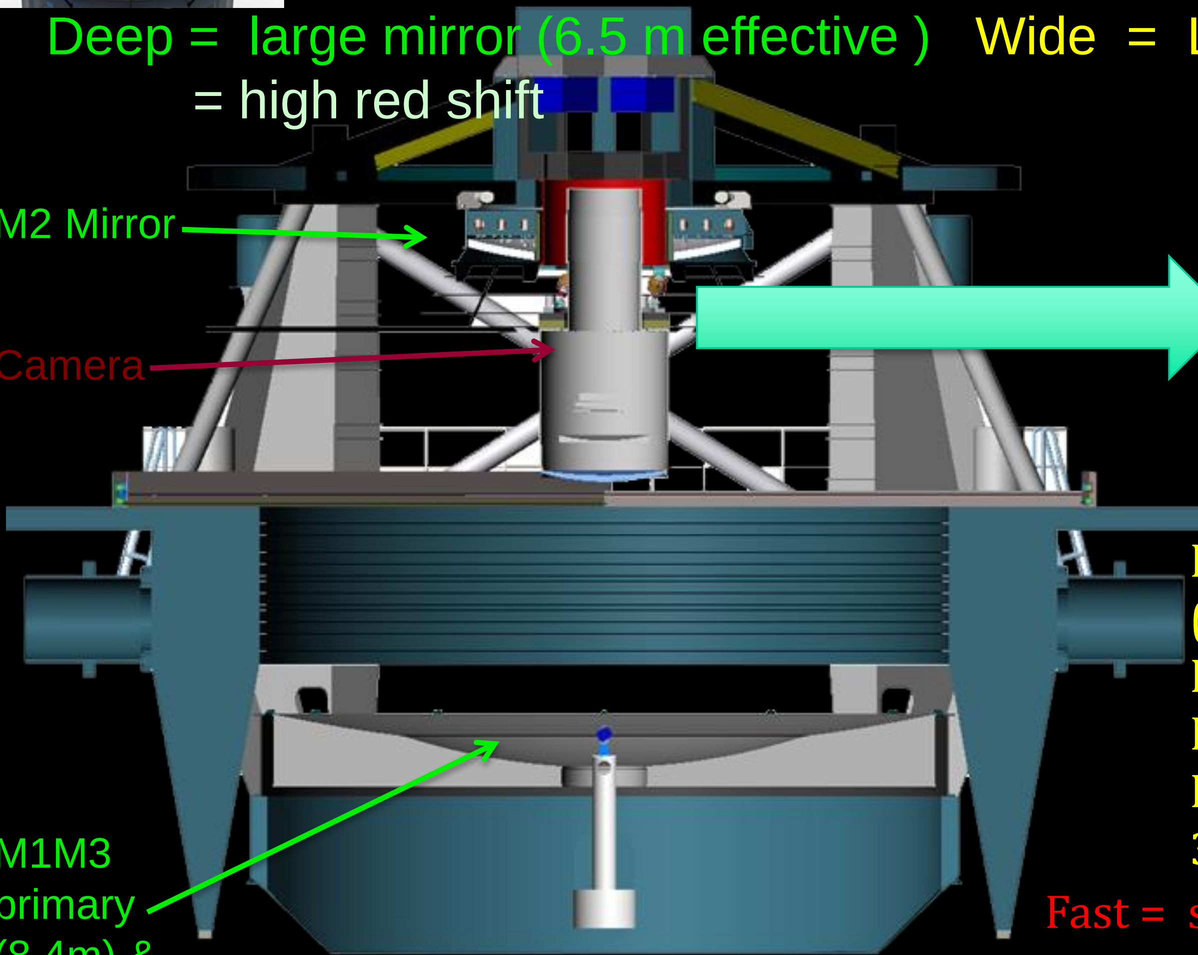
Today the key to increase the volume of universe observed (= Survey galaxies / year) is to increase the surface of detector used more than increasing the mirror size

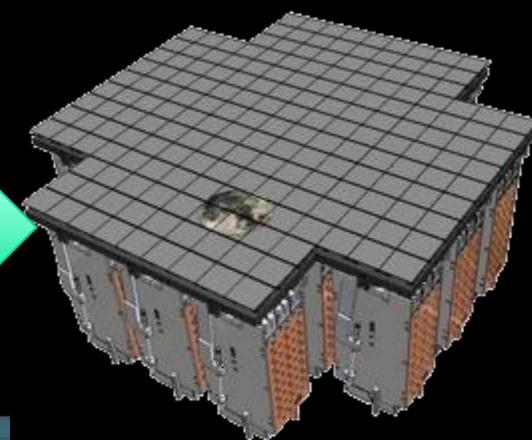


LSST: Wide Deep Fast

Deep = large mirror (6.5 m effective)
= high red shift

Wide = Large field of view (3.5 deg)





Field of view : 3.5 deg
(9.6 deg2 =.023% sky sphere)
Full moon : 0.5 deg
Focal plane diameter : 64 cm
For Science : 189 CCD
3024 Channels , > 3 G pixels

Fast = survey of the full visible sky
~twice a week
= exposure time 15s readout 2s
Annual data volume comparable to a LHC experiment!

Moving Structure 350 tons
60 tons optical systems

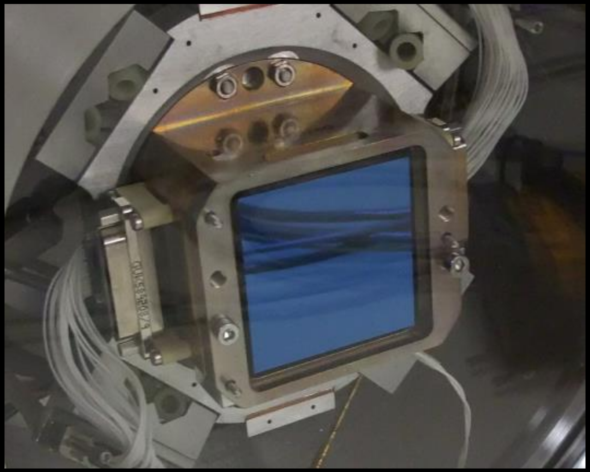
LSST camera : CCD

Today , following a strong R&D effort ,
2 vendors are considered for the LSST sensors

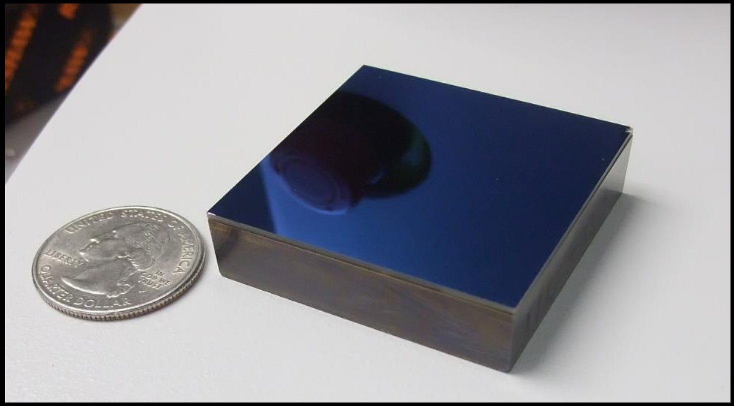
Science CCD candidate for LSST focal plane :

- E2v CCD 250 or ITL STA3800B
- 4kx4k , 10 µm pixels
- 100 µm deep depleted UV to IR sensitive
- 16 channels output for fast readout
- **High QE at 1000nm (35%)**
- **PSF << 0.7” (0.2”)**
- **Focal ratio f/1.2 (fast beam)**
  - Flat Detectors < 5µm p-v
- **Large focal plane**
  - Focal plane of ~ 3200 cm^2
  - 90% focal plane coverage
  - 4 side buttable package, sub-mm gaps
- **Fast readout (2 s)**
  - Segmented detectors (16 channels) ~3200 video channels on the focal plane
- **Low readout noise**

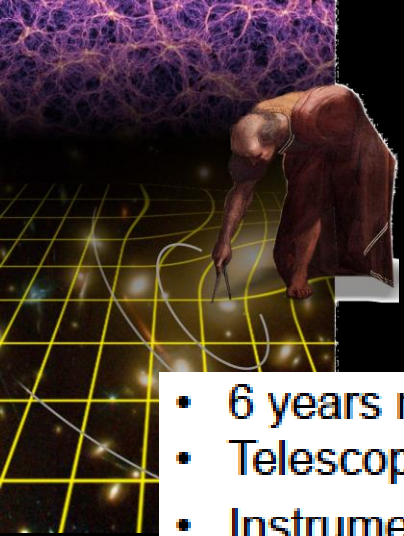
  < ~ 5-8 e- rms
- **Large dynamical range :** Full well 180 000 e-



e2v CCD250 (operable)

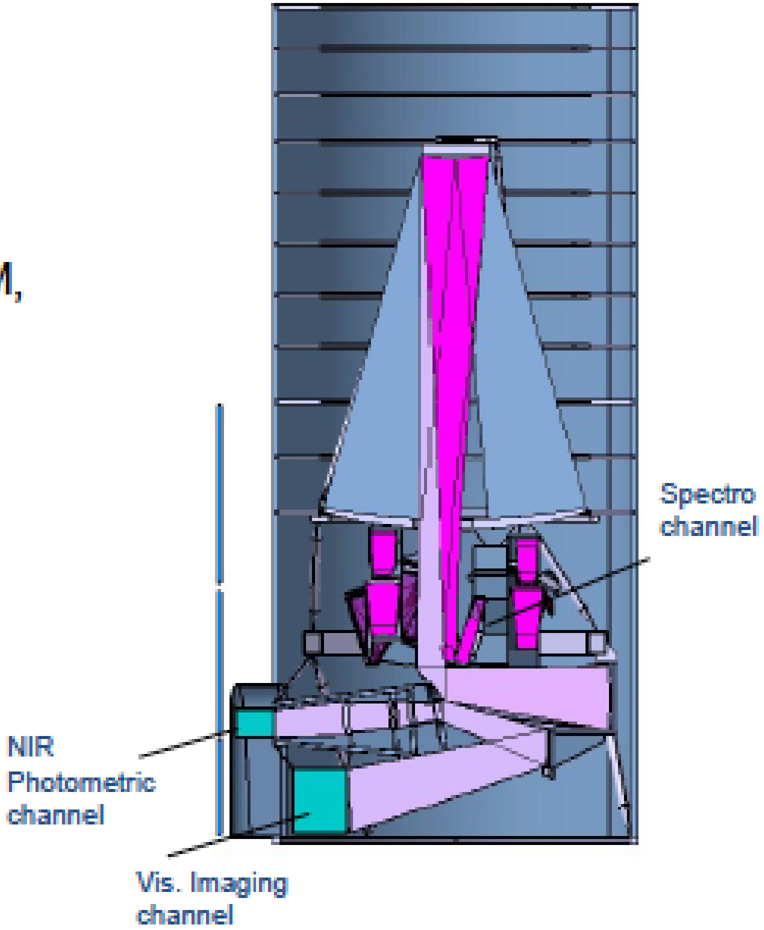


STA3800 (mechanical sample)



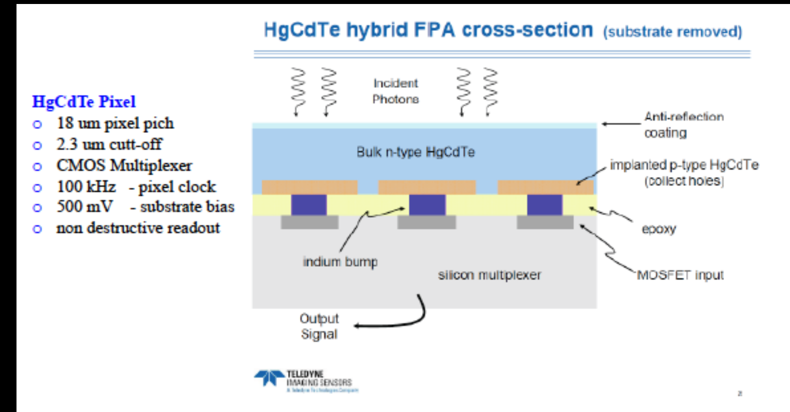
ESA mission Euclid

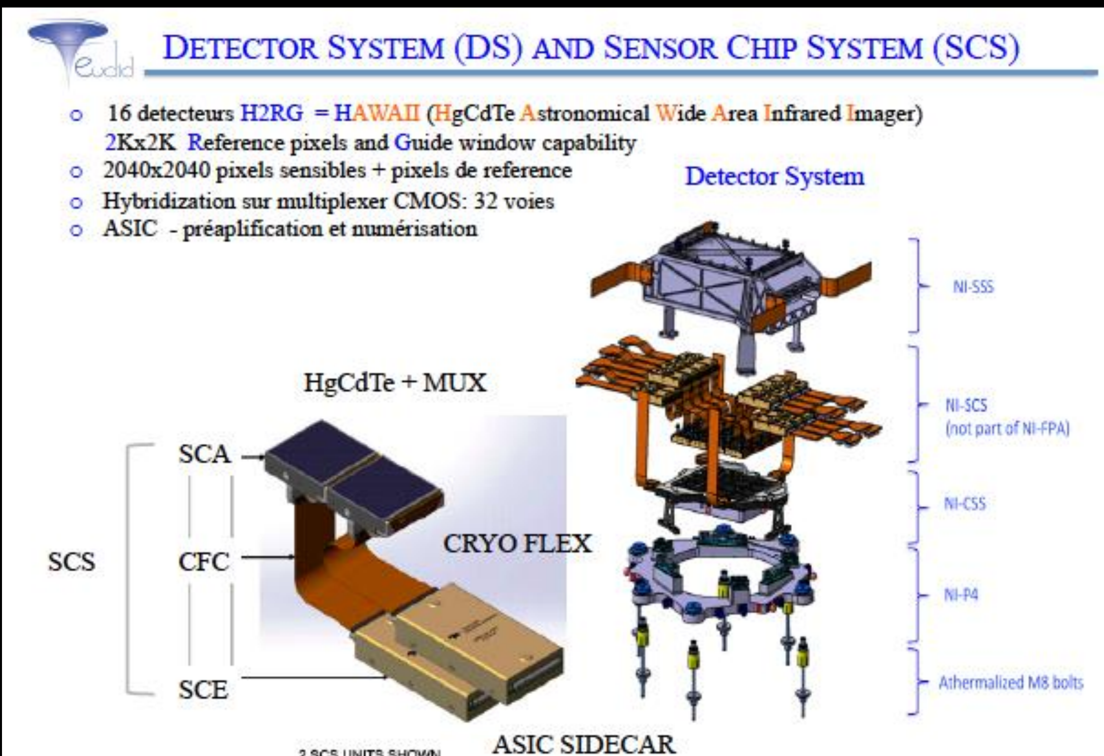
- 6 years mission
- Telescope: 1.2 m primary
- Instruments:
- **VIS**: Visible imaging channel:
  - 0.54 deg^2, 0.10" pixels, 0.16" PSF FWHM,
  - 1 broad band R+I+Z (0.55-0.92mu),
  - 36 CCD detectors, galaxy shapes
- **NISP**: NIR photometry channel:
  - 0.54 deg^2, 0.3" pixels,
  - 3 bands Y,J,H (1.0-1.7mu),
  - 9 HgCdTe detectors, photo-z's
- **NISP**: NIR Spectroscopic channel:
  - 0.54 deg^2,
  - R(moyenne)=350,
  - 0.9-1.7mu, slitless, spectro redshifts

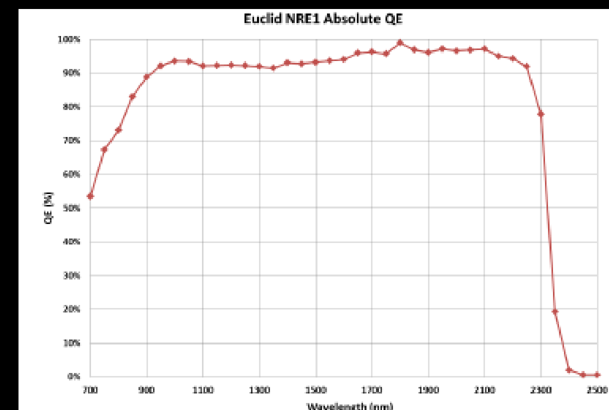


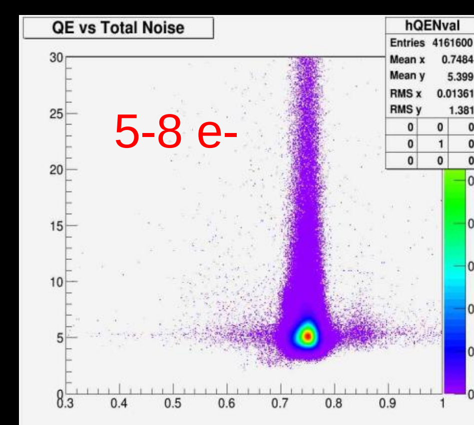
APPEC

NISP Instrument









- VERY GOOD detector performances demonstrated for 8 Engineering detectors (2.3um) produced by TELEDYNE under ESA contract
- Total Noise (Fowler 16 and 100s integration) AND QE are compliant for 95% of pixels with the NISP requirement

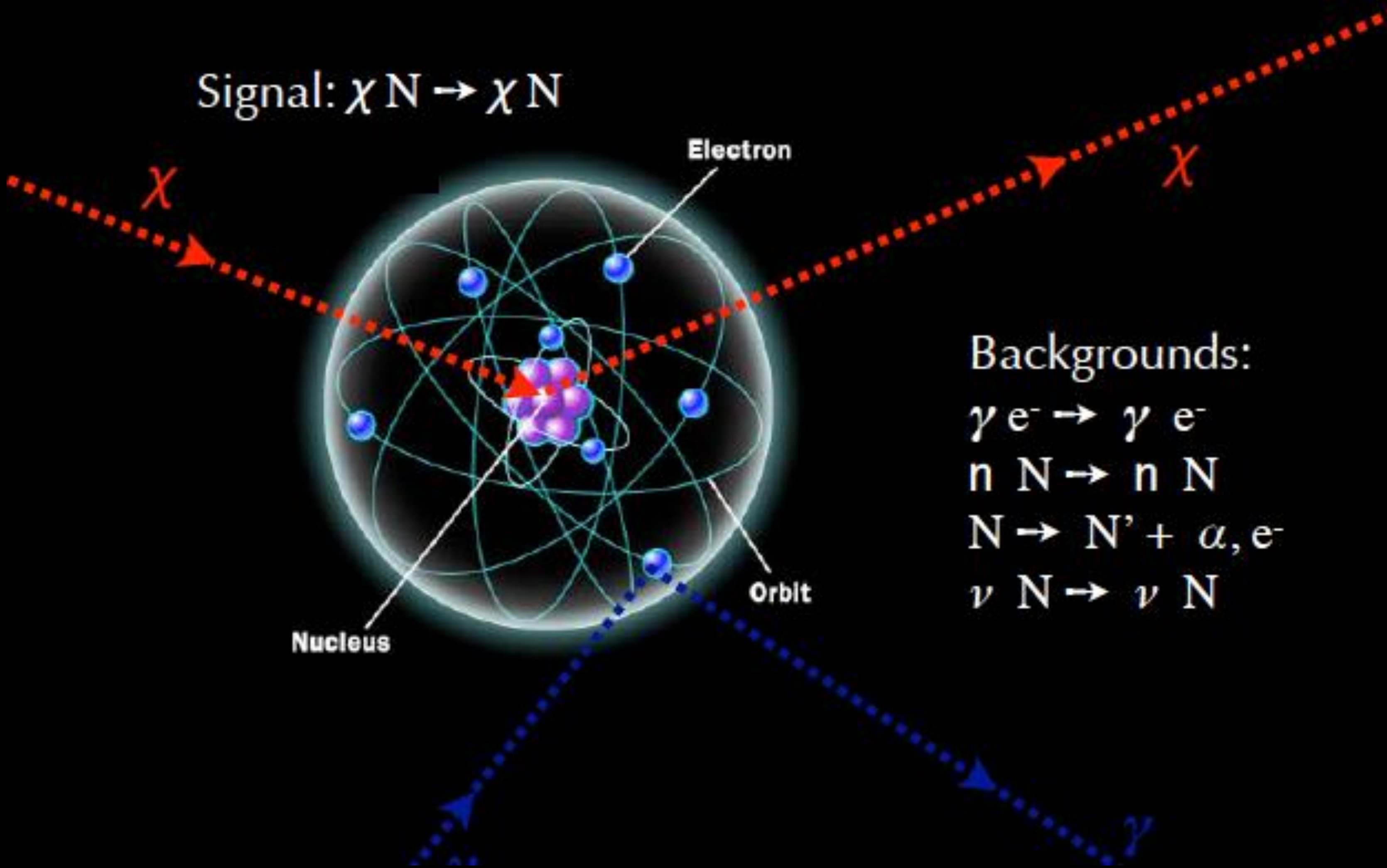
III. Dark matter searches

- Single phase noble liquids
- Double phase noble liquids
- Directional detection (with photodetector bias)

Many thanks to E. Aprile, L.Baudis, J. Monroe and T. Marodan-Unagoitia for this part

Dark Matter Direct Detection

Signal: $\chi N \rightarrow \chi N$



Backgrounds:

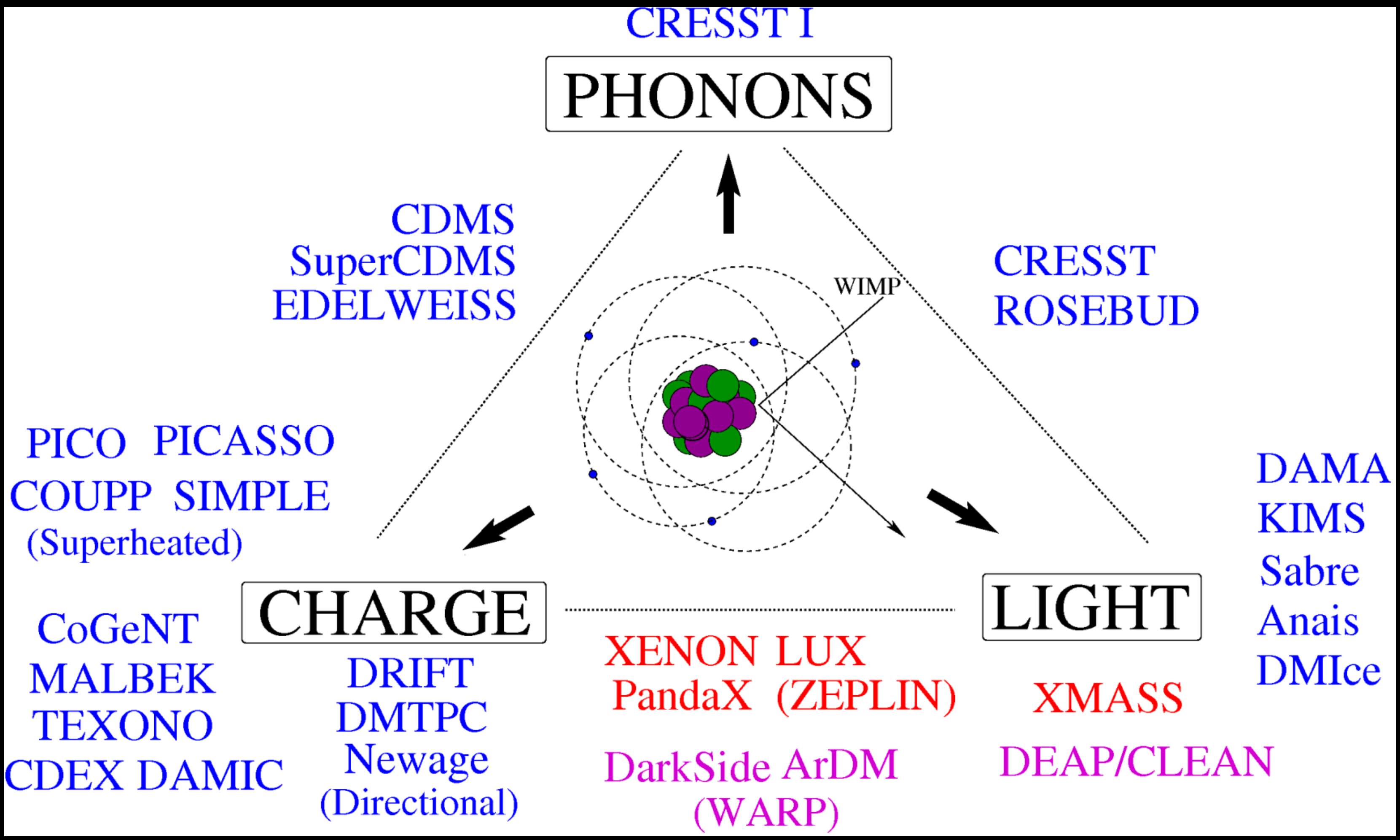
$\gamma e^- \rightarrow \gamma e^-$

$n N \rightarrow n N$

$N \rightarrow N' + \alpha, e^-$

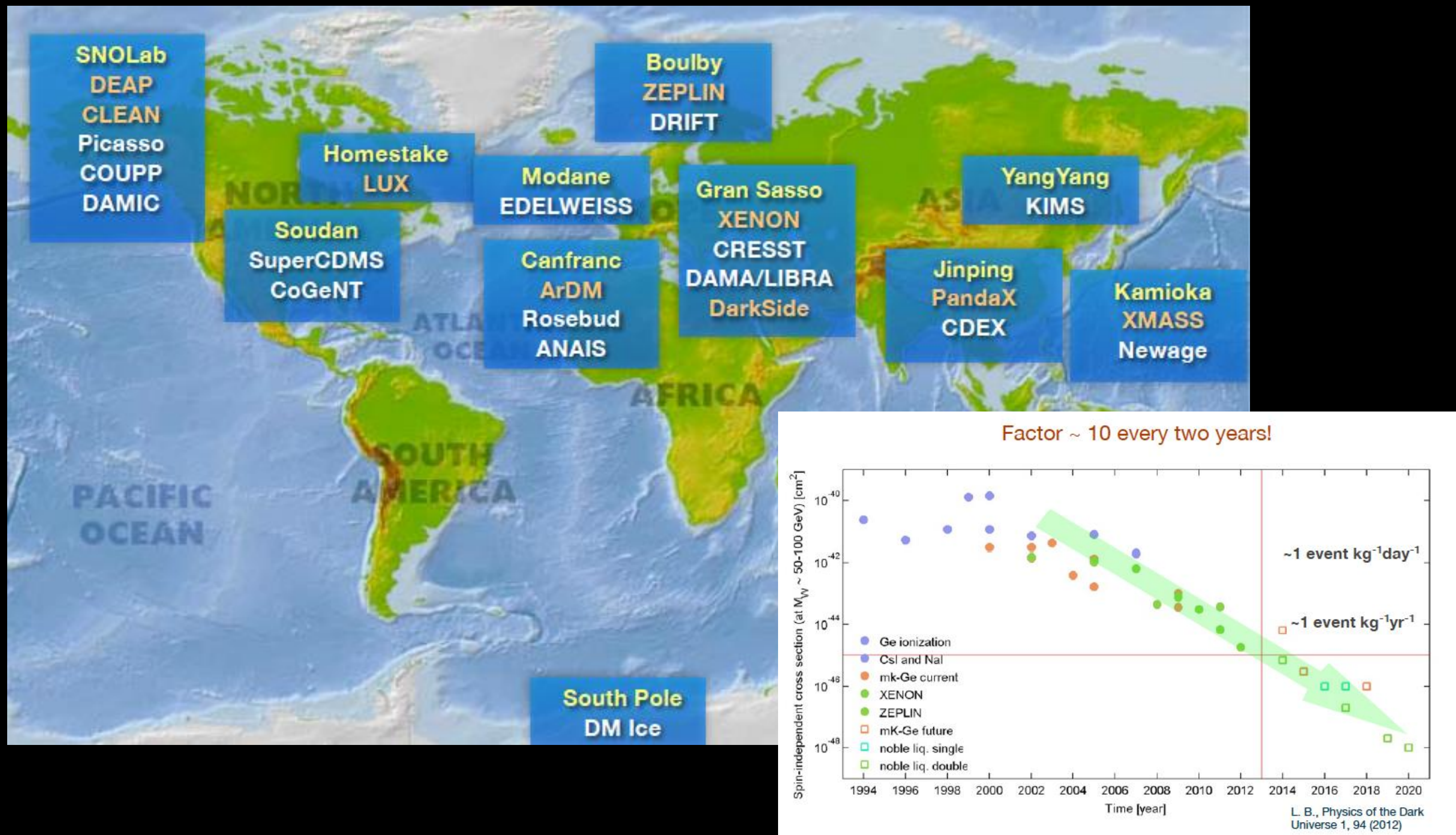
$\nu N \rightarrow \nu N$

APPEC



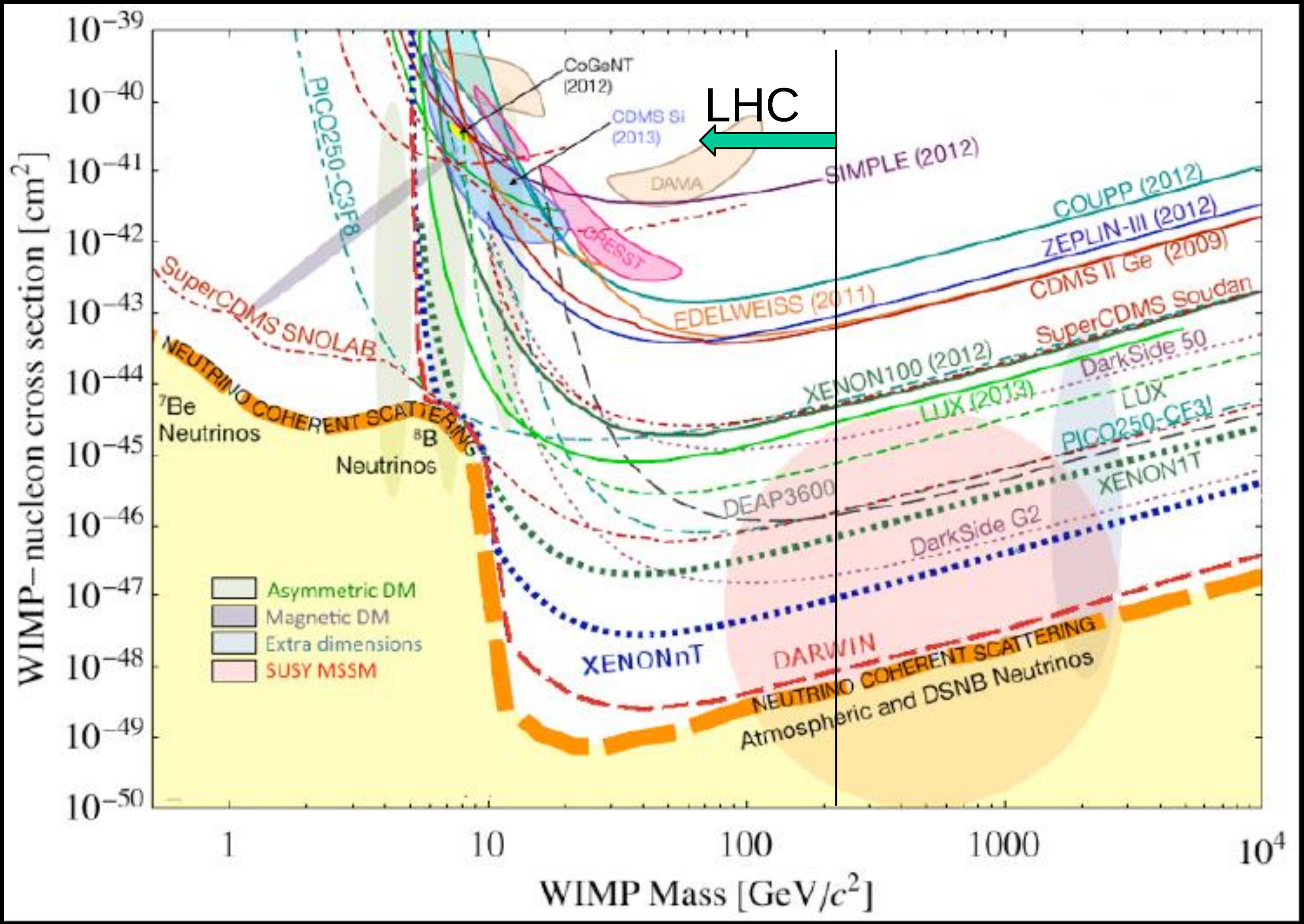
CRESST I
PHONONS
CDMS
SuperCDMS
EDELWEISS
WIMP
CRESST
ROSEBUD
PICO PICASSO
COUPP SIMPLE
(Superheated)
DAMA
KIMS
Sabre
Anais
DMIce
CHARGE
LIGHT
CoGeNT
MALBEK
TEXONO
CDEX DAMIC
DRIFT
DMTPC
Newage
(Directional)
XENON LUX
PandaX (ZEPLIN)
XMASS
DarkSide ArDM
(WARP)
DEAP/CLEAN

Direct dark matter detection
Competition and progress



APPEC Roadmap: WIMPs will be put in a severe, if not conclusive, test during the next 10 years. (LHC, direct and indirect detection). In case of discovery both accelerator and non-accelerator experiments will be needed to determine the physical properties of WIMPS.

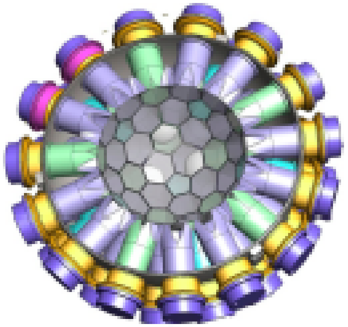
Direct Dark Matter direct detection

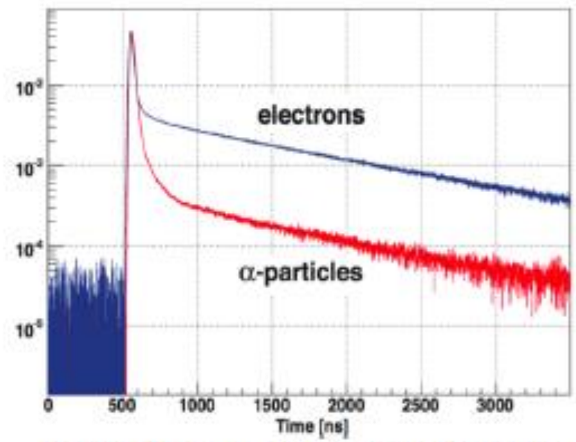


- ✓ *Complementarity: Low masses ➔ bolometers , High masses ➔ Noble liquids*
- ✓ *Complementarity with LHC but also in case of high WIMP masses rationale for FCC*
- ✓ *Reaching the neutrino background ➔ directional R&D*
- ✓ *Place for 1-2 in the world, with large international collaborations*
- ✓ *APPEC SAC ➔ Decide after 3 years the (G3) multi-ton experiment.*
- ✓ *P5 similar conclusions*

Single phase noble liquid detectors

- High light yield using 4π photosensor coverage
- Position resolution in the cm range
- Pulse shape discrimination (PSD) from scintillation





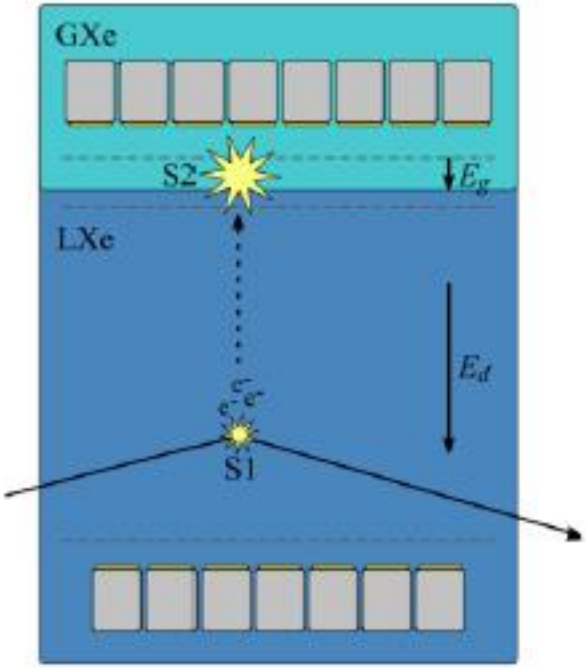
Scintillation decay constants of argon measured by ArDM

- 800 kg of LXe in single phase (self-shielding)
- Ultra-low absolute background required
- 1st DM run → unexpected BG from PMTs found
- Detector refurbished, resumed data-taking

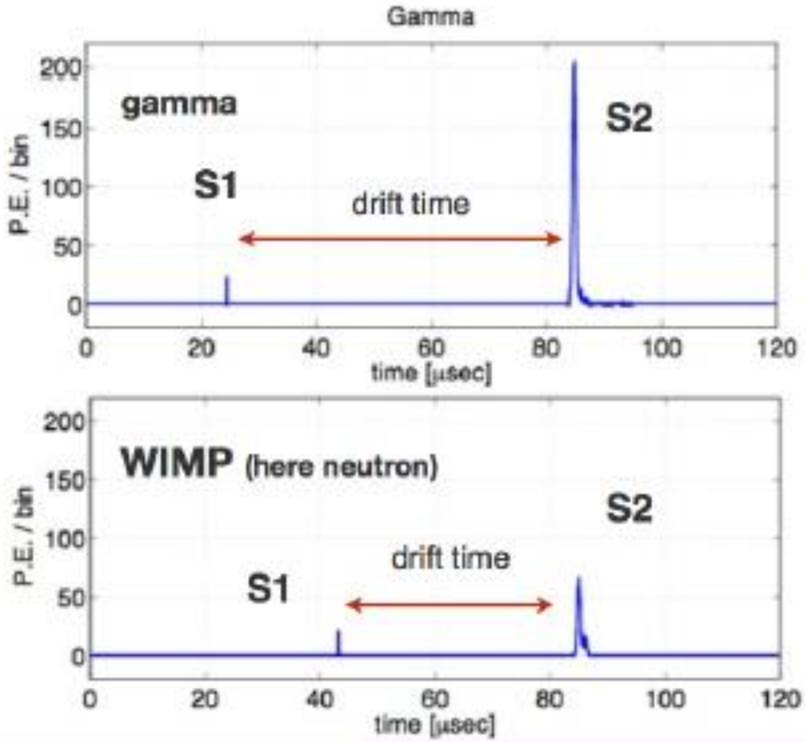
Two phase noble liquid TPC

- Scintillation signal (S1)
- Charges drift to the liquid-gas surface
- Proportional signal (S2)

→ Electron- /nuclear recoil discrimination



- Drift field necessary ~ 1 kV/cm
- Electronegative purity required
- Position resolution in mm

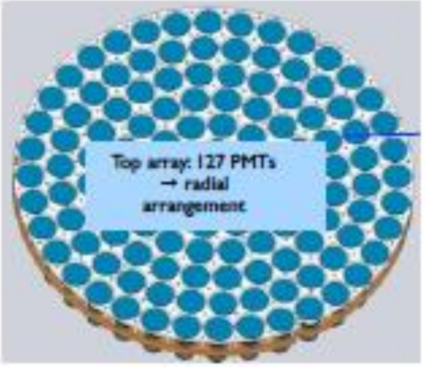


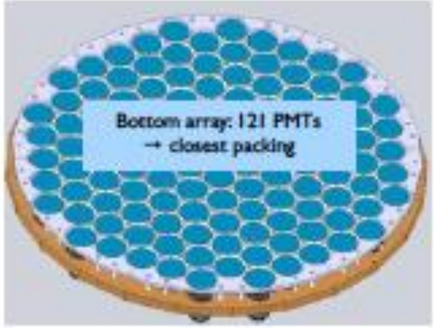
The XENON1T inner detector

- PMTs are screened with HPGe, then tested in cold gas and - a subsample - in LXe
- TPC design is finalized, currently under prototyping, materials being screened

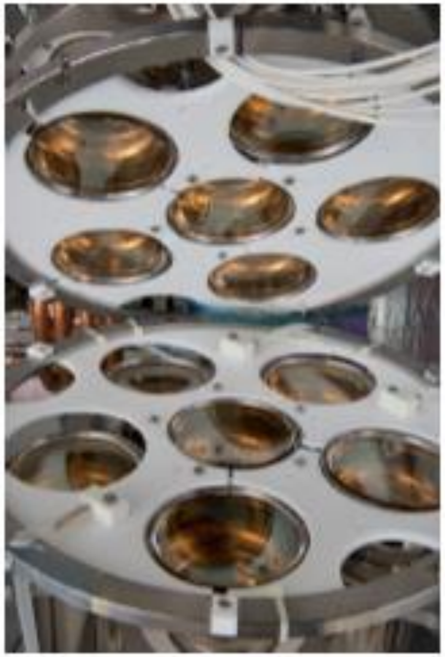
The TPC

127 3" sensors top





121 3" sensors bottom

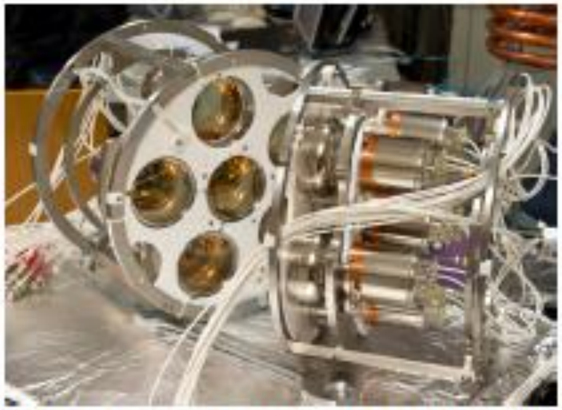


R11410-21 3-inch PMTs; average QE at 175 nm: 36%, average gain: 3×10^6 at 1500 V

Light sensors for noble liquid dark matter experiments

- Requirements for a dark matter experiment:
  - Low radioactivity & low dark rate (background rate only few Hz!)
  - UV sensitivity & stable performance at cold temperatures
  - Low power consumption & high QE/CE
- APD, SiPMT, hybrid tubes (SiGHT) ...

  See contributions in Dark matter & Photon sessions
- State of the art 3" photomultipliers from Hamamatsu:
  - R11065 (for LAr) used by DarkSide
  - R11410 (for LXe) for XENON1T, PandaX and LZ



XENON1T testing setup for R11410-21 at MPIK

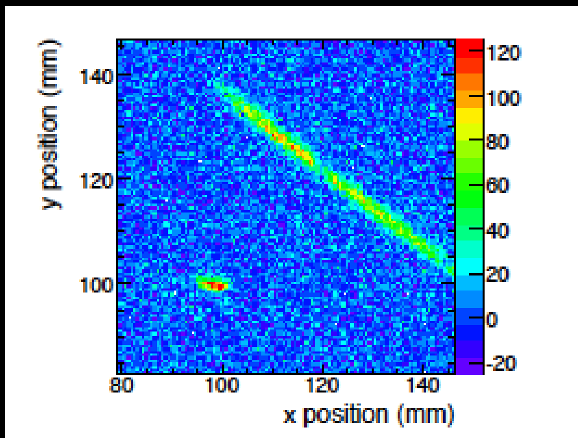
- Low-radioactive photosensors

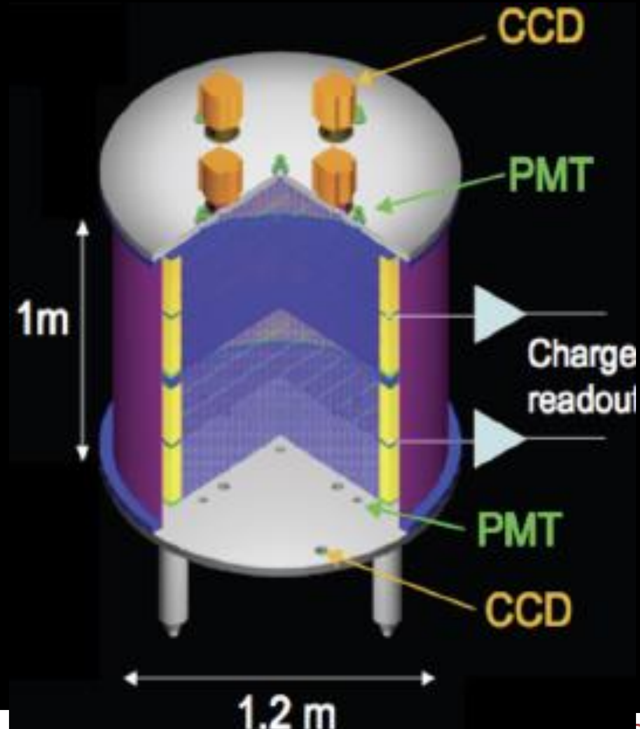
  ^{238}U & ^{228}Th < 1 mBq/PMT

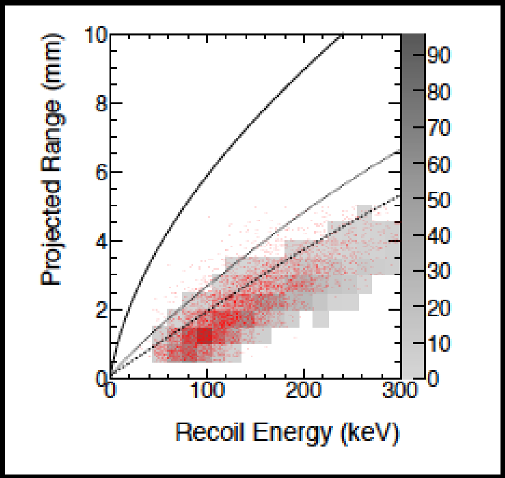
  For reference: 1 Banana $\sim$ 15 Bq in ^{40}K
- High quantum efficiency: 36 % in average for XENON1T
- Stable performance at $-100°C$

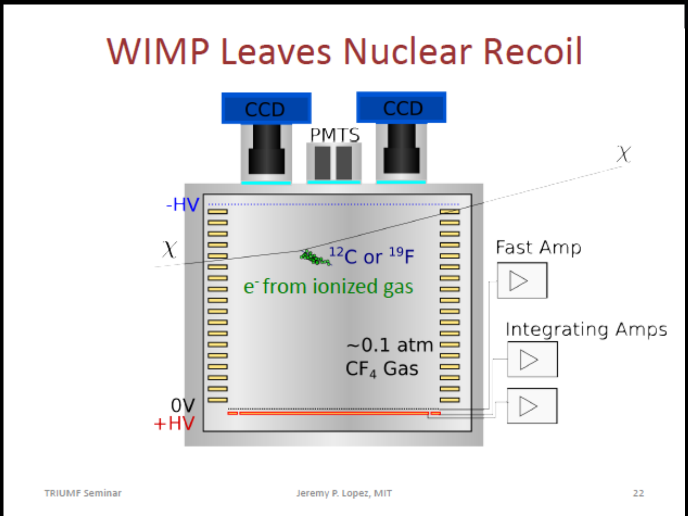
Directional detection

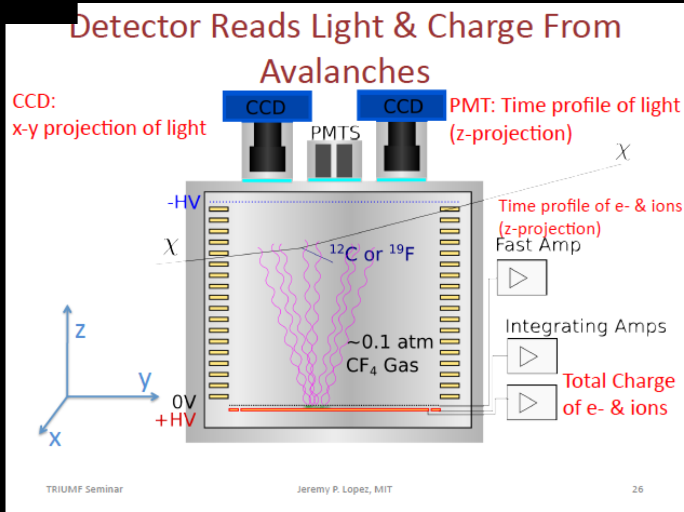
An exemple : DMTPC a mixture of PMT and CCDs









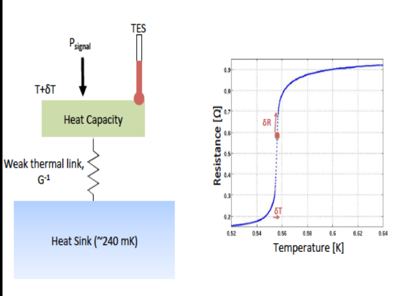


IV Dark matter with bolometers and CMB polarisation studies

➔ Transition Edge Sensors (TES)

➔ Kinetic Inductance Detectors (KID)

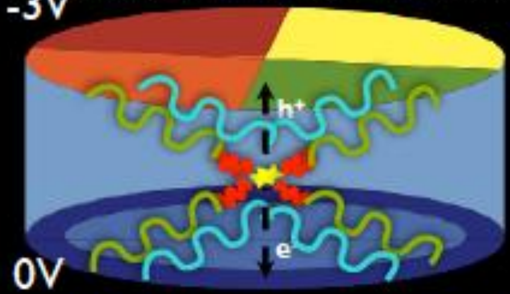
Many thanks to A. Tartari and M. Piat for this part



Bolometers
EDELWEISS(LSM) and CDMS (SOUDAN)

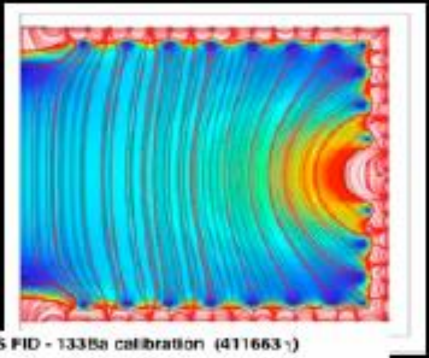
Transition Edge Sensors, operated at ~40 mK on Ge and Si crystals

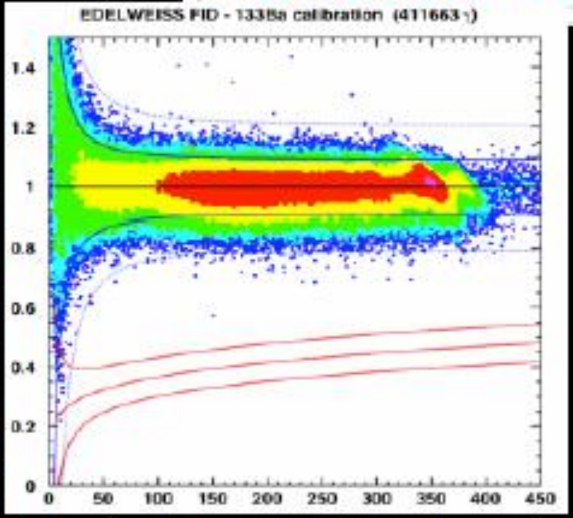
Phonon side: 4 quadrants of phonon sensors for energy & position (timing)



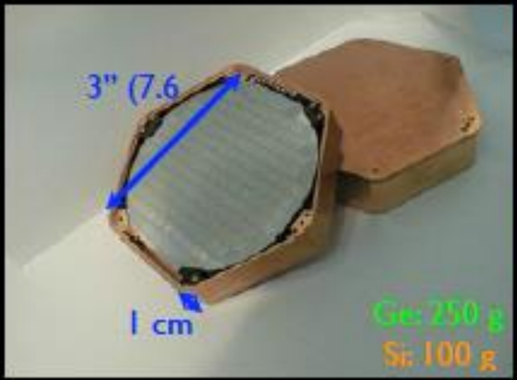
Charge side: 2 concentric electrodes (inner & outer) energy (& veto)

CDMS re-design a la EDELWEISS to reduce surface backgrounds x10^4

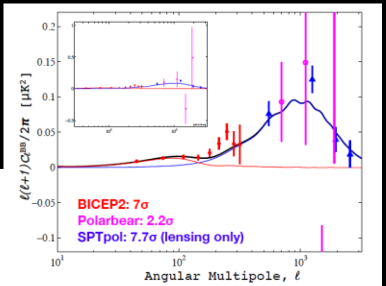


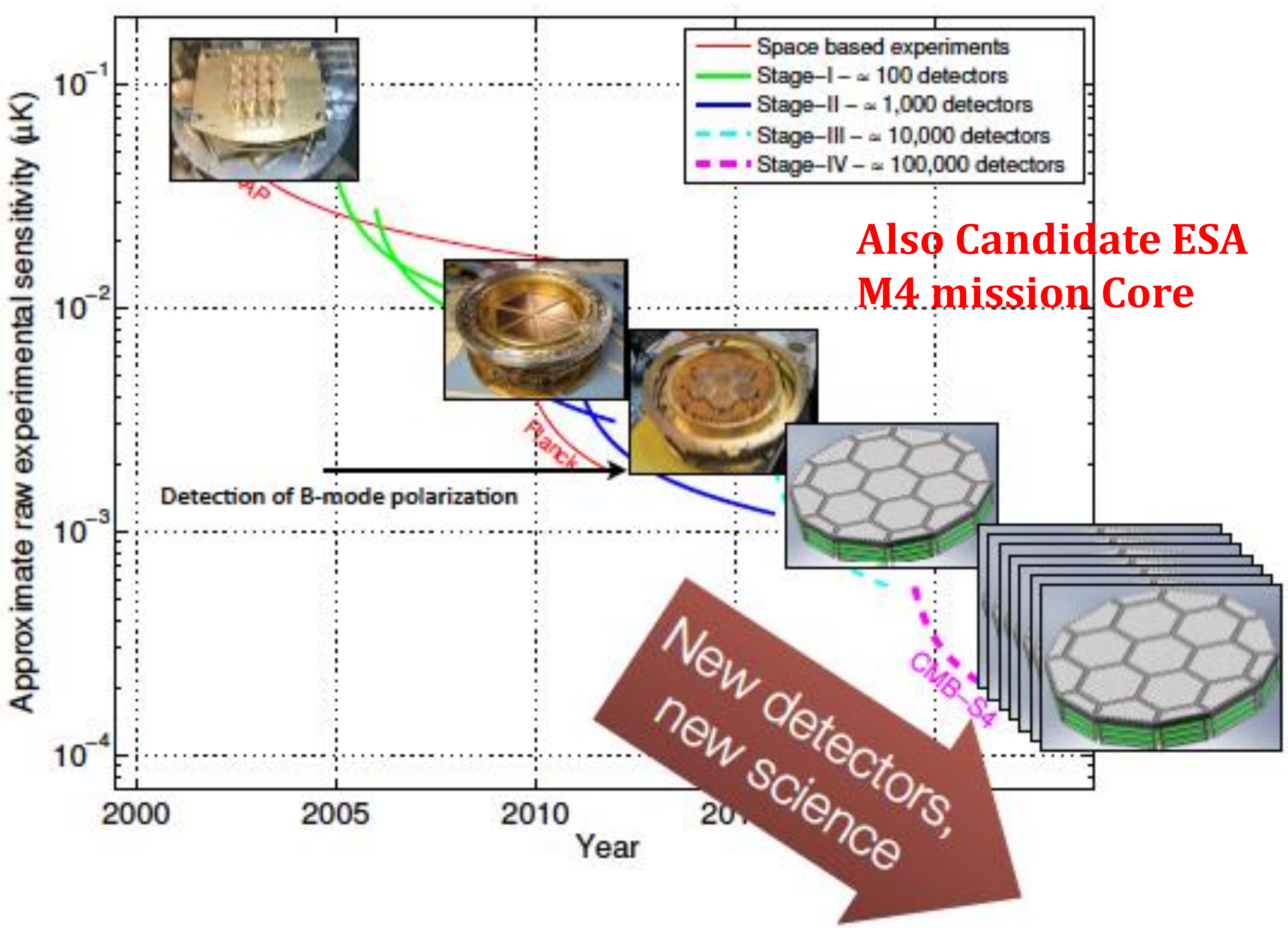


Ionization/Phonon yield vs. E_{recoil} (keV)



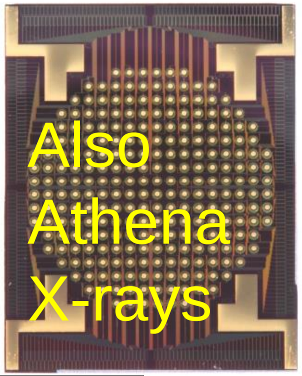
TES detectors in CMB B-polarisation studies





Also Candidate ESA M4 mission Core

256-pixel X-ray calorimeter

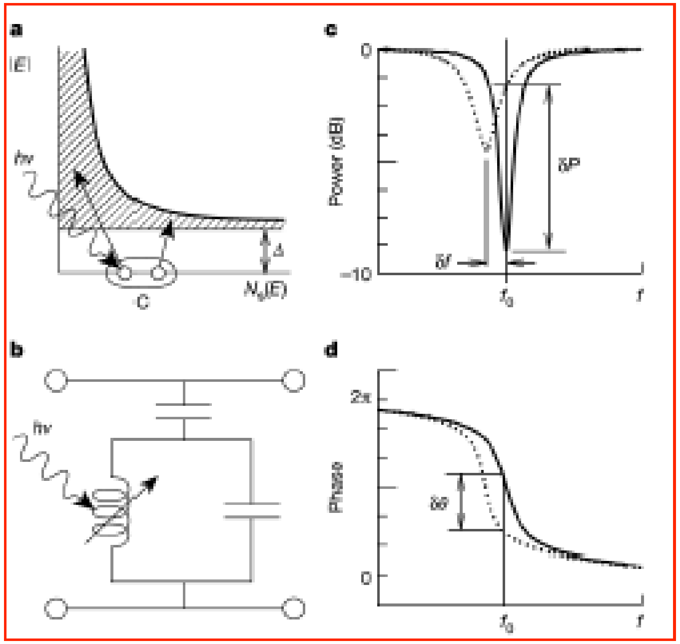


A new KID (Kinetic Inductance Detector) in the block

Principle:

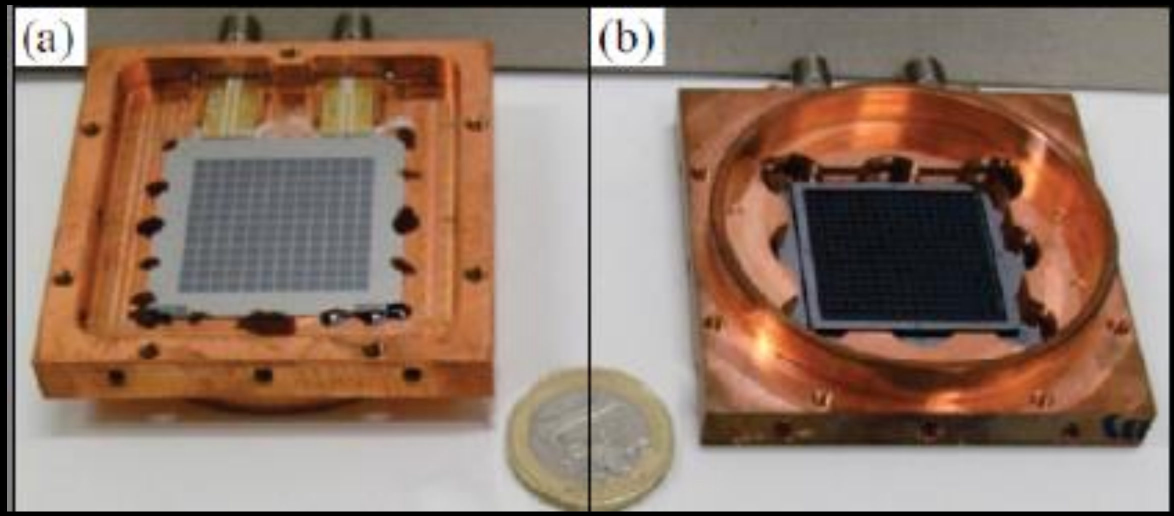
- In a superconducting metal cooper pairs move in a coherent way and store a significal amount of kinetic energy: $U_K=1/2L_KI^2$.
- An incoming photon breaks the Cooper pair increases the kinetic inductance and pushes the resonance of an LC circuit to lower frequency changing its amplitude.
- If the detector (resonator) is excited with a constant on-resonance microwave signal, the energy of the absorbed photon can be determined by measuring the degree of phase and amplitude shift. ➔ concurrent spectroscopy
- Naturally multiplexable

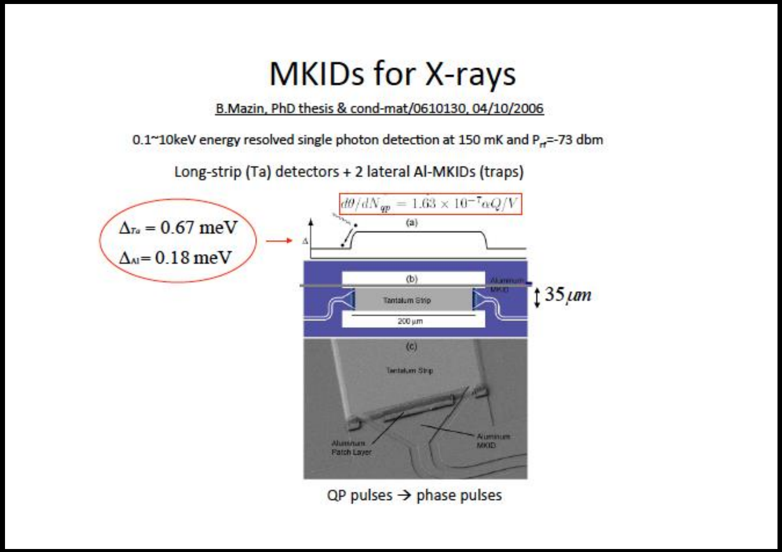
Credit: P. Day et al. Nature 2003

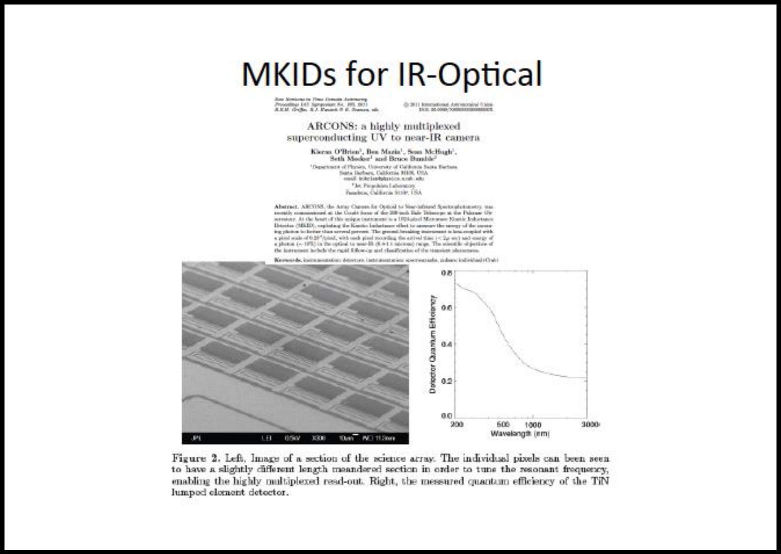


KID possibilities

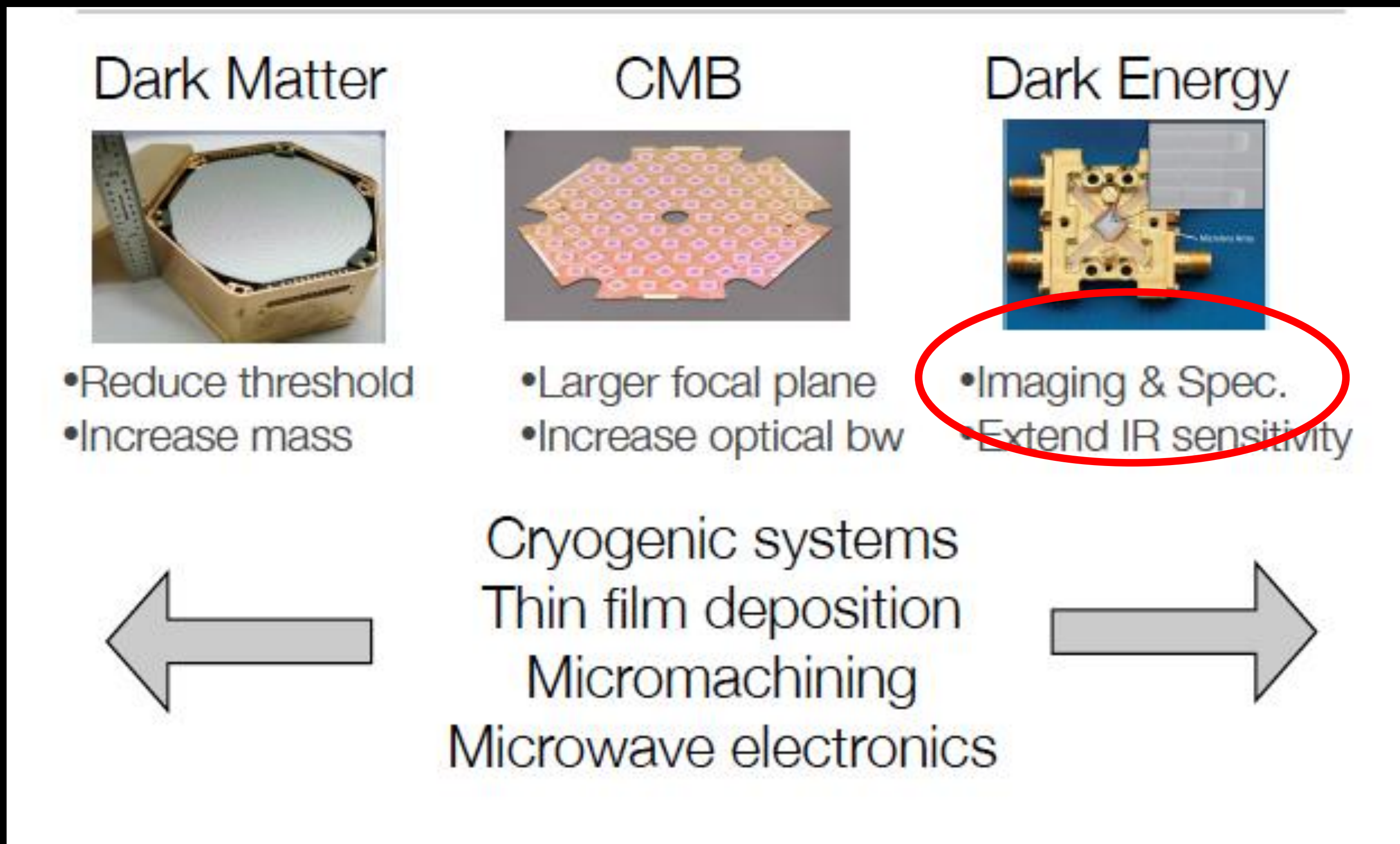
An MKID mm detection 100 GHZ NIKA (Europe)







A large synergy of superconductive detectors
Towards the new CCD?



From the Snowmass P5 process

Conclusions

- *Astroparticle Physics experiments are driving innovation in photodection*

I. *High energy and Large neutrino detectors*
   - *We are at the 100_300 K "pixel" level*
   - *Classic Photomultipliers hold well the stage.*
   - *SiPM make their way for smaller implementations*
   - *Innovative methods for distributing timing across large arrays*
   - *Large surveys for dark energy and astronomical dark matter increase coherence*
- *Large Surveys*
   - *Gigapixel arrays , towards LHC-style data rates*
   - *Important developments in NIR with Euclid*

III. *Direct dark matter and neutrino-less double-beta decays*
   - *Low radioactivity photodetection, cryogenic operation*

IV. *Cosmology and Dark Energy*
   - *Bolometers inaugurate superconducting detector technology*
   - *TES promising technology for very large CCD-type arrays for CMB*
   - *MKIDs promise synchronous imaging and spectroscopy, large multiplexing , lower costs .*

APPEC

APPEC TECHNOLOGY FORUM ON PHOTOSENSORS

22-23 APRIL 2015

PAST ASPERA actions on the Industrial front

Photosensors and Electronics	(Munich October 2010)
Mirrors and Lasers	(Pisa Oct ober 2011)
Cryogenics and Vacuum	(Darmstadt March2012)

Venue: Carl-Friedrich von Siemens Stiftung, Schloss Nymphenburg, Munich

Participants: Project scientists, Technology experts from industry, funding agencies

Topics

- What are the requirements of the coming projects concerning photosensors?
- What are the technological challenges?
- What products are available and what kind of R&D activities are required?
- Is there an R&D strategy that can be commonly followed by research institutes and SME?
- What is the impact of developments on other scientific fields or market ready products?

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