THE VISION OF PHOTON COUNTING IN THE NEXT DECADE

VACUUM AND GASEOUS SENSORS

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ASTROPARTICLE PHYSICS IS A VERY EXCITING PLAYGROUND

→ MANY EXISTING EXPERIMENTS (FANCY NAMES)

→ MANY RESULTS AND DISCOVERIES

→ MANY COLLABORATORS AND AGENCIES

→ GREAT POTENTIAL –
MANY NEXT-GENERATRION PROJECTS PROPOSED

→ PROBLEMS: DREAMS vs. REALITY

MY FOCUS → ON THE KEY PROBLEM
AND POSSIBLE SOLUTIONS

FUNDAMENTAL, GROUNDBREAKING INSRUMENT DEVELOPMENTS AND INVENTIONS SOMETIMES BECOME RECOGNIZED

The Nobel Prize in Physics 2009 ~ astroparticle

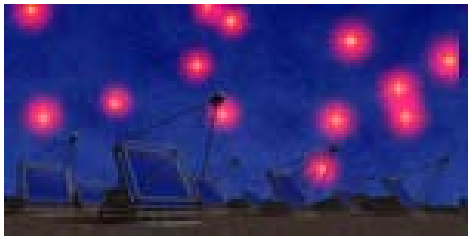
Willard S. Boyle and George E. Smith
Bell Laboratories, Murray Hill, NJ, USA
"for the invention of an imaging semiconductor circuit – the CCD sensor"

The (TRIPPLE) Nobel Prize in Physics 2002 = astroparticle

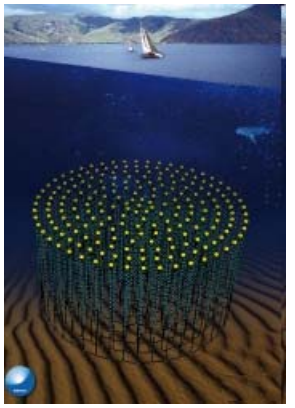
"for pioneering contributions to astrophysics, in particular for the detection of cosmic neutrinos"
Raymond Davis Jr. and Masatoshi Koshiba
"for pioneering contributions to astrophysics, which have led to the discovery of cosmic X-ray sources"
Riccardo Giacconi

GEORGES CHAPACK

ASPERA – the MAGNIFICENT 7

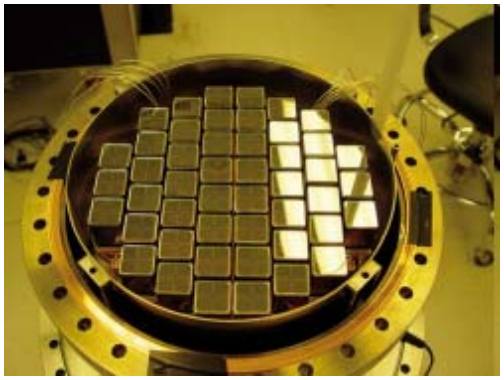


1. **CTA, a large array of Cherenkov Telescopes for detection of cosmic gamma rays (>> MAGIC+HESS)**
2. **KM3NeT, a cubic kilometer-scale neutrino telescope in the Mediterranean**



3. **Ton-scale detectors for dark matter search**
4. **A ton-scale detector for the determination of the fundamental nature and mass of neutrinos**

5. **A Megaton-scale detector for proton decay's search, neutrino** astrophysics & investigation of neutrino properties,**supernova neutrinos**
6. **A large array for the detection of charged cosmic rays (AUGER NORTH)**

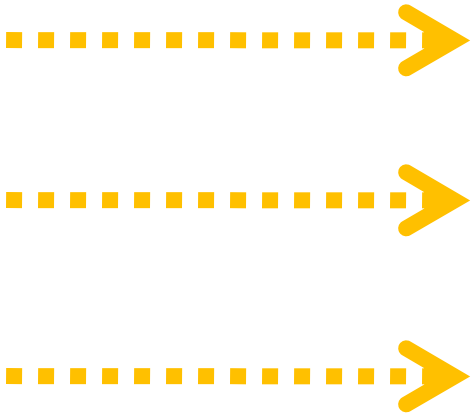


7. **A third-generation underground gravitational antenna**

Luminosity

LHC

ASTROPARTICLE



DETECTOR
=
TARGET

TWO FUNDAMENTAL PROBLEMS WITH

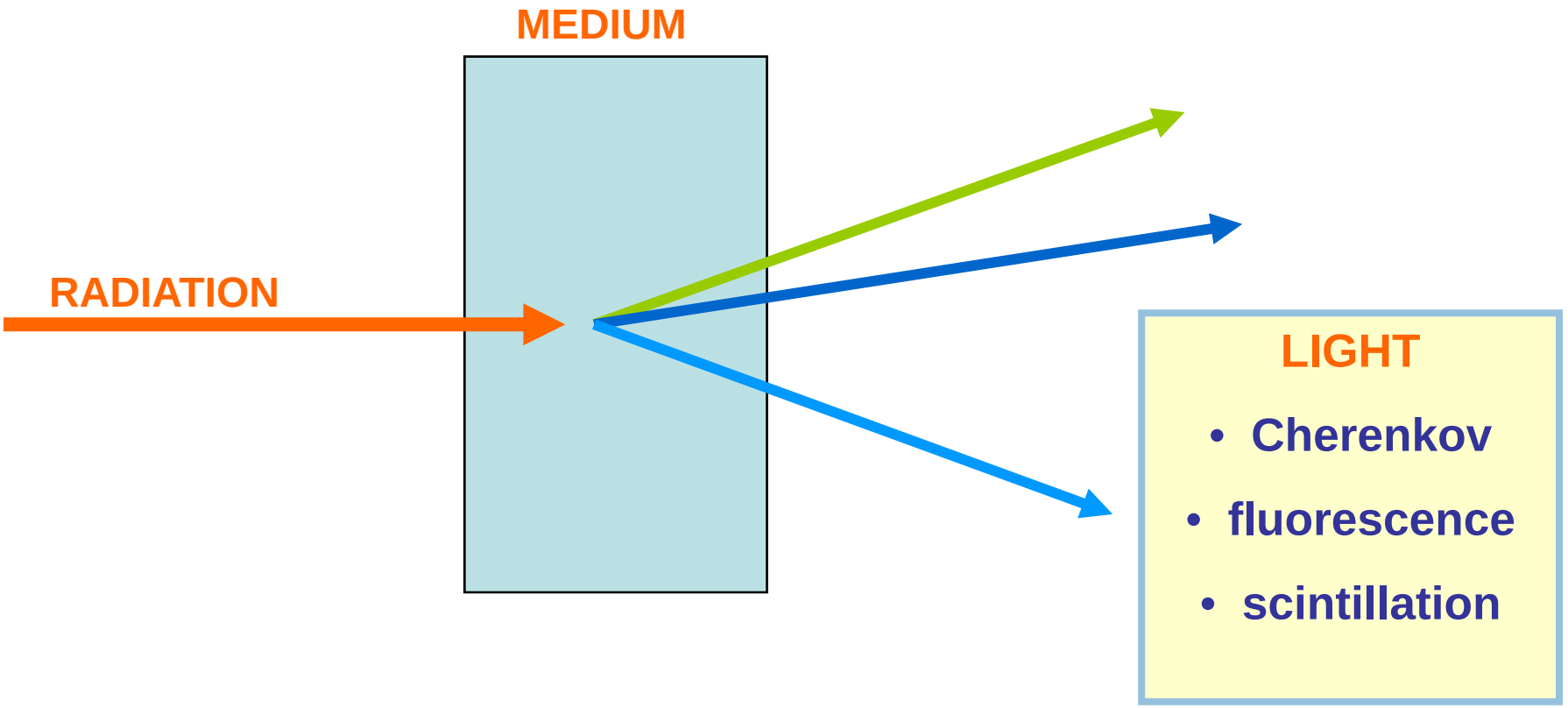
DETECTOR
=
TARGET

(Luminosity)

1. **THE NEEDED SIZE**
   → **The only remaining materials: the atmosphere, water, ice, mineral oil, LAr, LXe**

2. **A BAD GUY – Mr. Liouville:**
   he makes photon detection difficult and expensive

PHOTON DETECTION – KEY TECHNOLOGY (AND KEY PROBLEM)

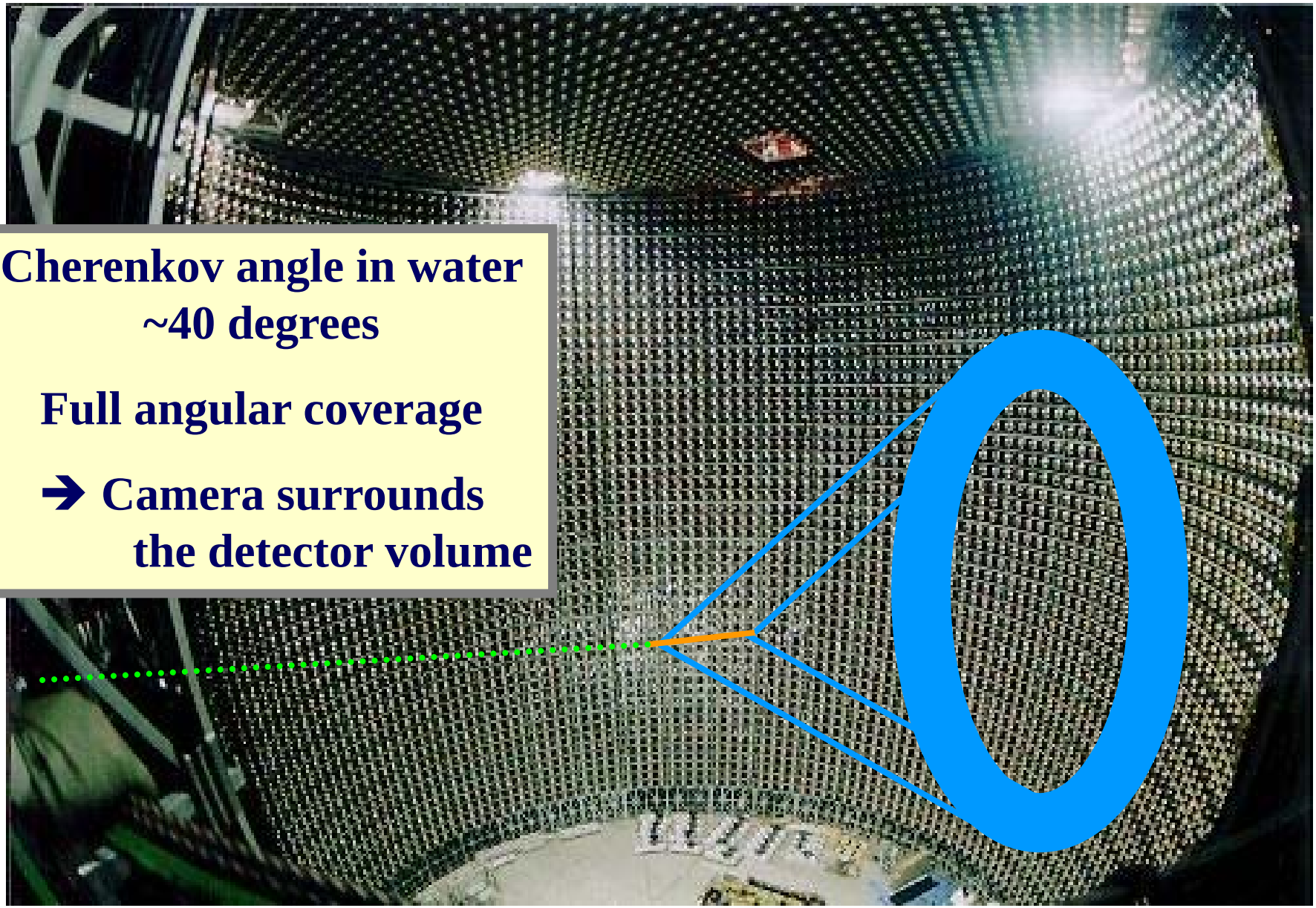


RARELY OCCURING PHENOMENA → SUPER-LARGE DETECTORS
→

ONLY NATURAL TRANSPARENT MEDIA ARE POSSIBLE

Water, Ice, Atmosphere, Mineral Oil

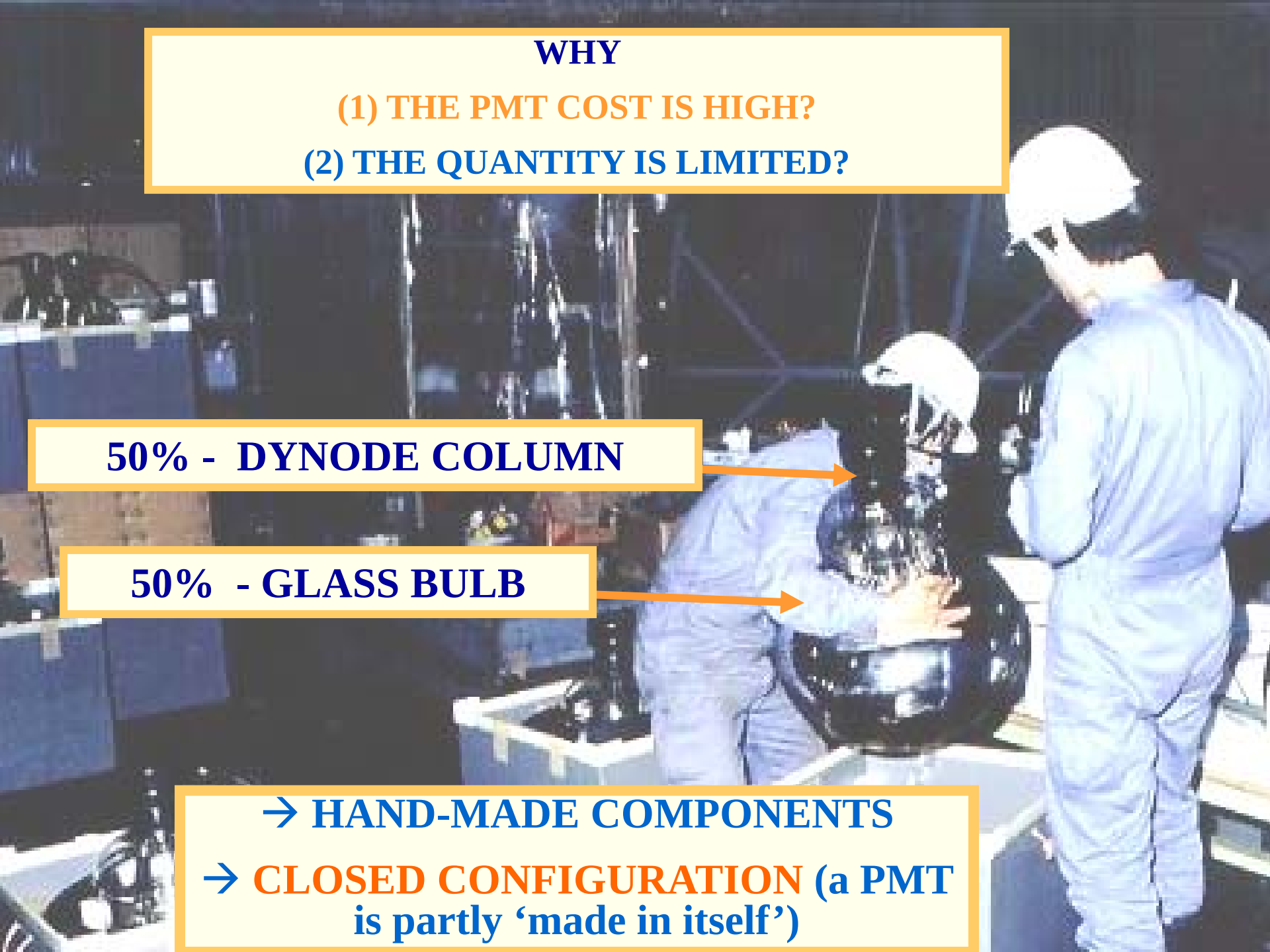
The Unbeatable Reality of Mr. Liouville



Cherenkov angle in water ~40 degrees

Full angular coverage

➔ Camera surrounds the detector volume



WHY

(1) THE PMT COST IS HIGH?

(2) THE QUANTITY IS LIMITED?

50% - DYNODE COLUMN

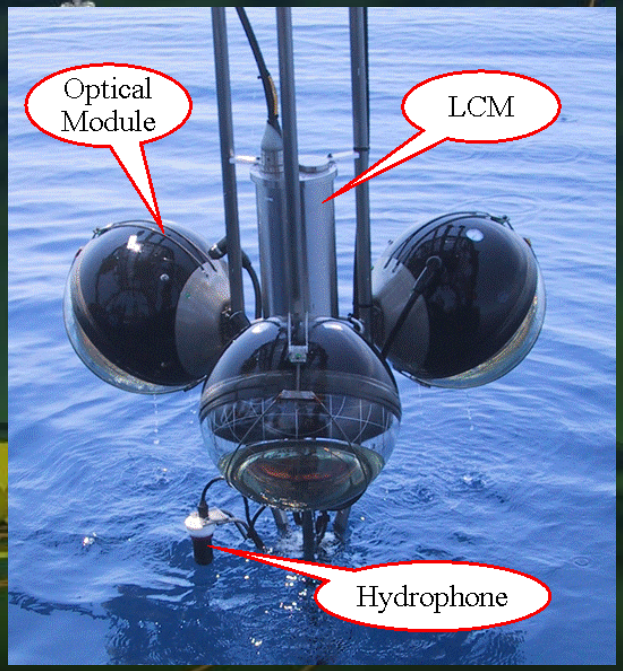
50% - GLASS BULB

→ HAND-MADE COMPONENTS

→ CLOSED CONFIGURATION (a PMT is partly 'made in itself')

ANTARES, under-water detector

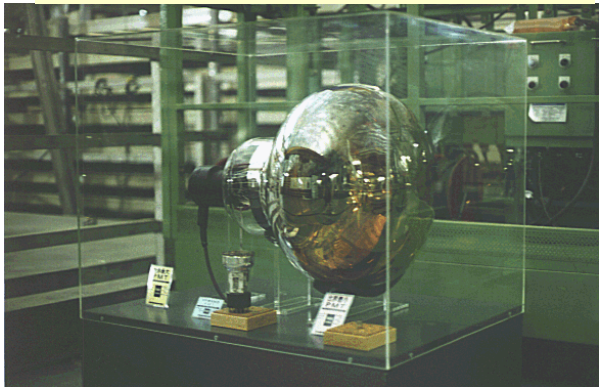
885 10” PMTs



Hallewell

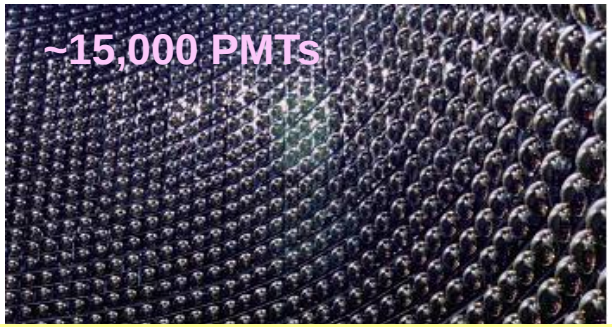
LARGE VOLUME RARE-EVENT EXPERIMENTS

SK Φ500mm Vac. PMT



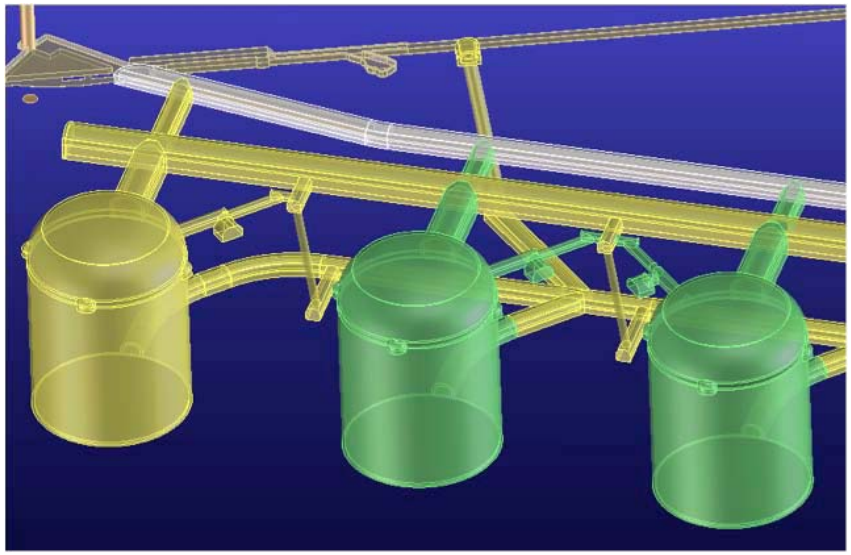
ALL PRODUCERS OF LARGE PMTs
(except Hamamatsu, ET?)
VANISHED!

WHO CAN PRODUCE?
WHO CAN AFFORD????
NEED NEW TECHNOLOGIES!



HYPER-K, LENA…> 100,000 PMTs!

Fermilab Long Baseline Neutrino Experiment LBNE



300,000 m^3 WATER + PMTs
12,000 m^2 of photon detectors per Each vessel

Cherenkov angle in air < 1 degree, also well defined observational direction, and small angular spread in the EM shower

➔ **Liouville's theorem allows significant beam area reduction**

➔ **Camera can have a small area**

MAGIC Telescope Inauguration, October 10 2003. (Photo-W. Ko)

NATURE (via Mr. Liouville):

Irreducibly Large Illuminated Area

In Astroparticle Experiments

Strong internal signal concentration

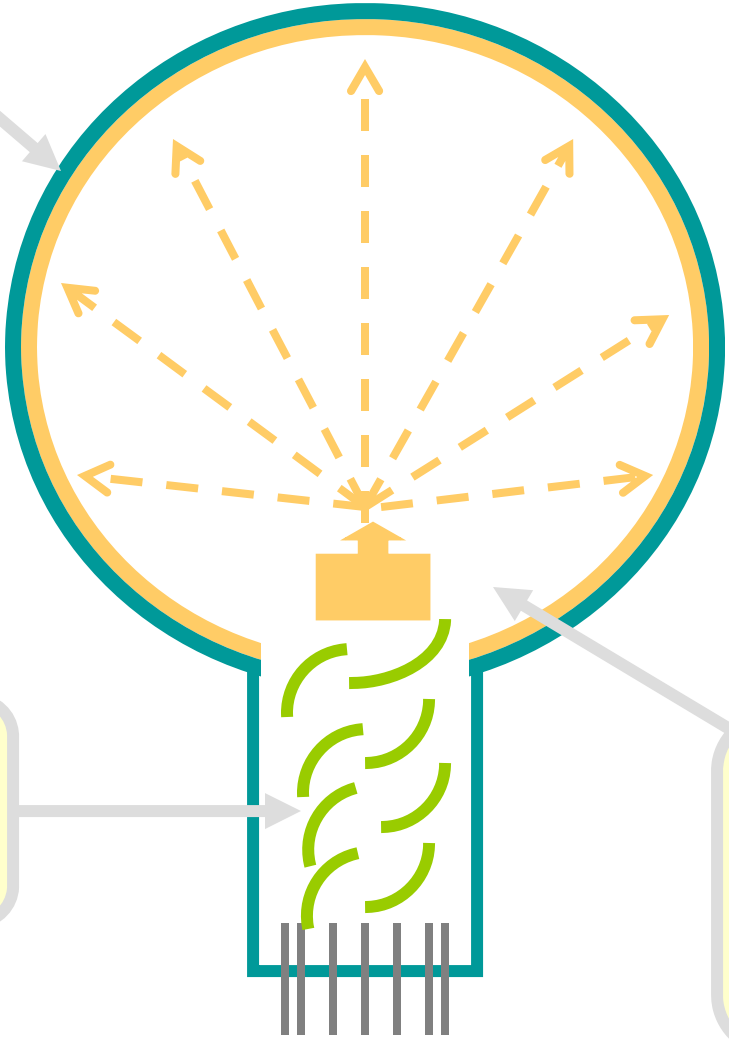
Vacuum + EM Forces

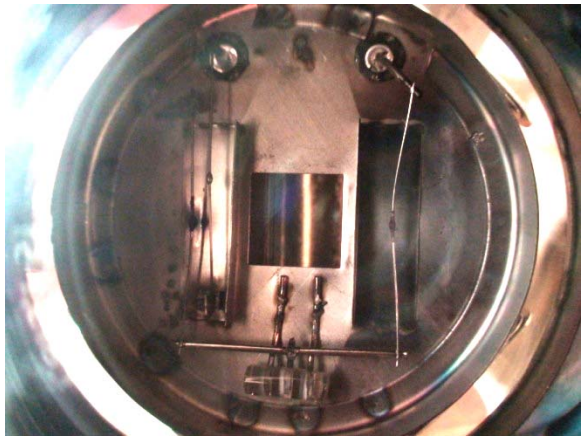
(photon → photo-electron → 'no more Mr. Liouville*')

(*) for those photons

PMTs – 1960's Technology

~handmade



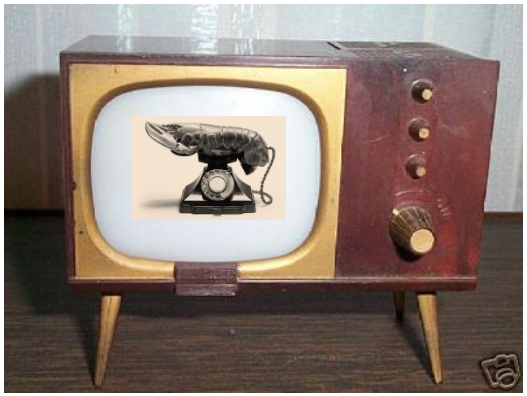


~handmade

Cs, K, Na, Sb
Sources remain inside!

WITH A FINE TOUCH OF A GENIUS

Development of Other Vacuum Devices



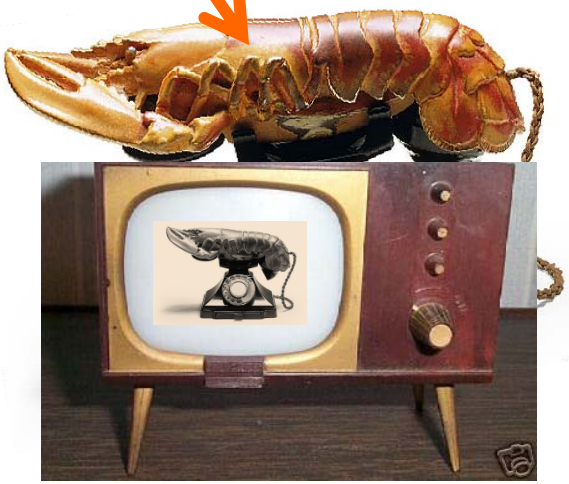
~1960

~2000

Production Cost ‘07 < $500/m^2

Development of Other Vacuum Devices

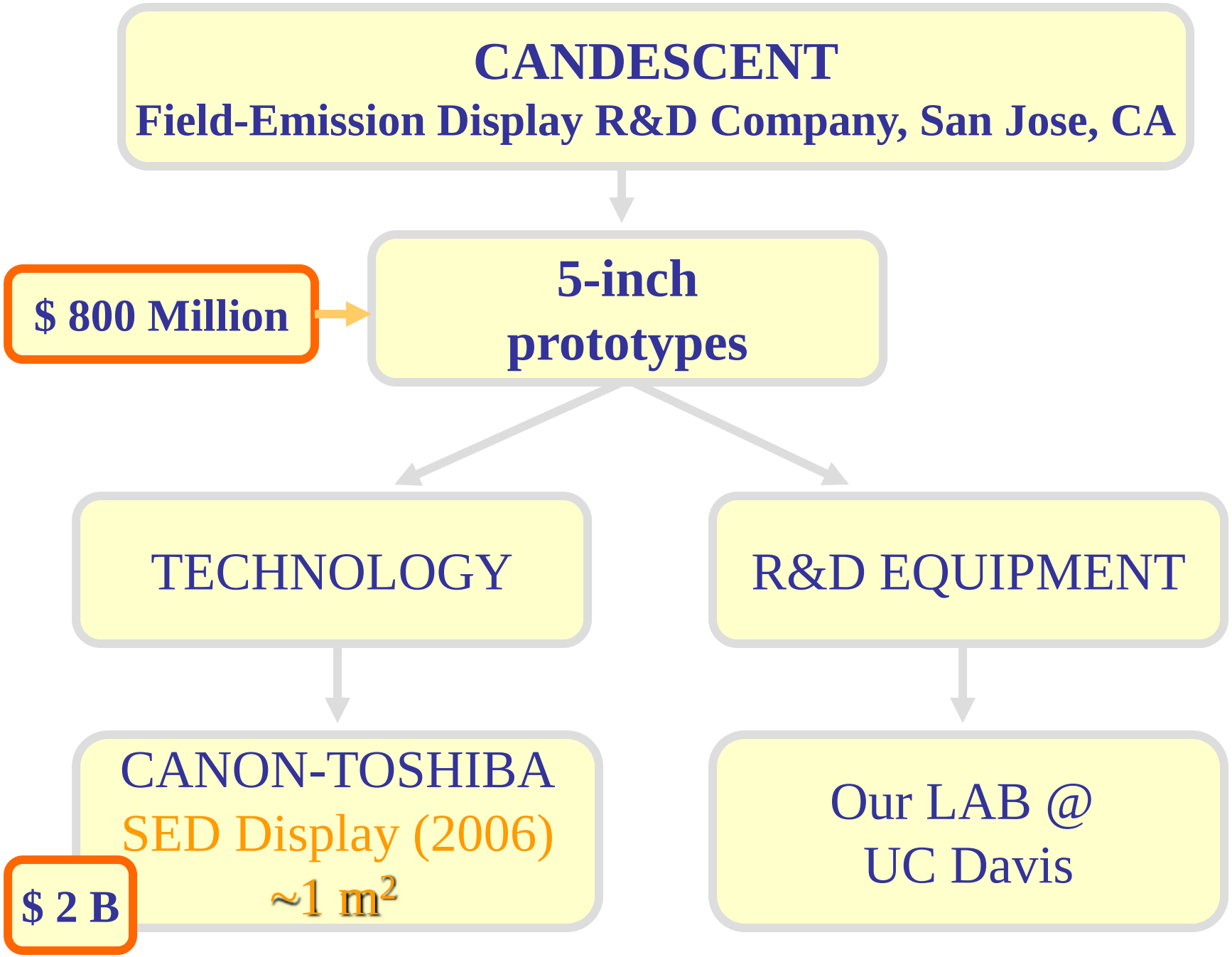
2010-2020 ?



~1960

~2000

Production Cost ‘07 < $500/m^2


CANDESCENT
Field-Emission Display R&D Company, San Jose, CA
$ 800 Million
5-inch
prototypes
TECHNOLOGY
R&D EQUIPMENT
CANON-TOSHIBA
SED Display (2006)
~1 m2
$ 2 B
Our LAB @
UC Davis

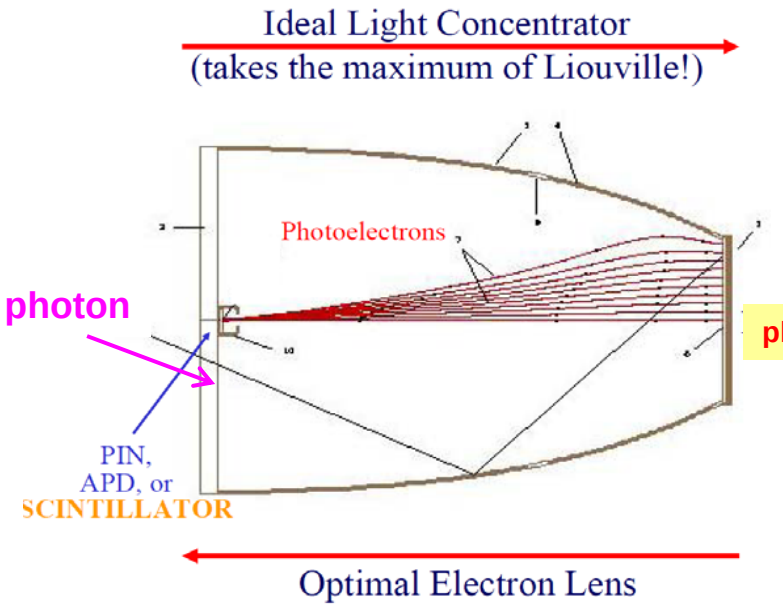
Market-oriented view of rare and/or weak radiation phenomena

- **Nuclear Nonproliferation and Homeland Security**
- **Widely Accessible Medical Diagnostics (PET, SPECT, gamma cameras)**
- **Proton Decay**
- **Neutrino Physics**
- **Geo-neutrino Physics**
- **Neutrino Astrophysics**
- **Gamma-ray Astronomy**

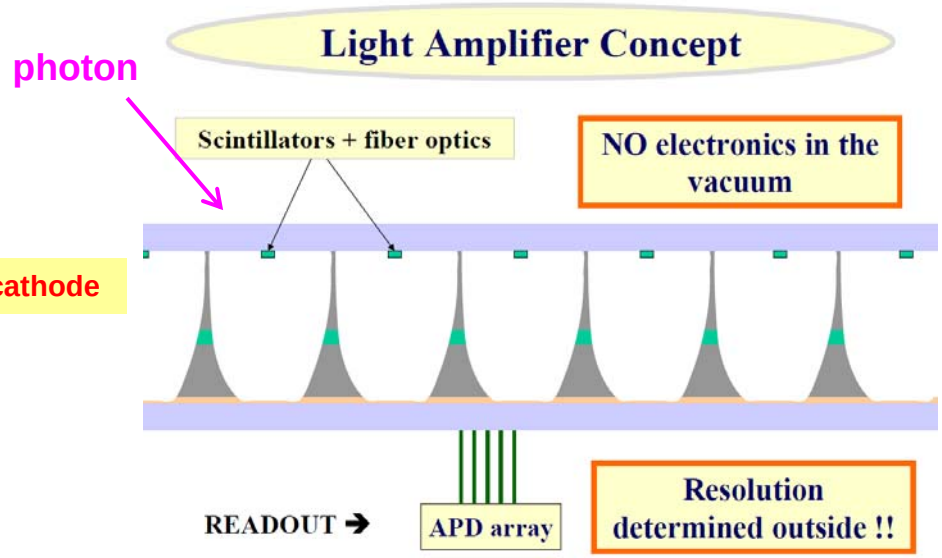
  (low detection threshold + wide acceptance angle)
- **Ultra-high energy cosmic rays (>10^{19} eV)**
- **Neutrinoless Double Beta Decay (e.g. SuperNemo)**
- **Dark Matter Search… ETC.**

LARGE-AREA VACUUM PHOTON DETECTORS?

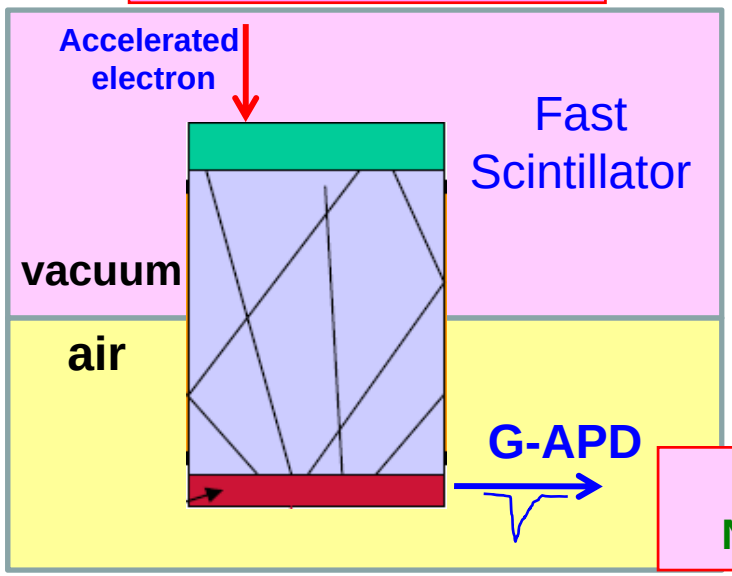
Ferenc LIGHT06

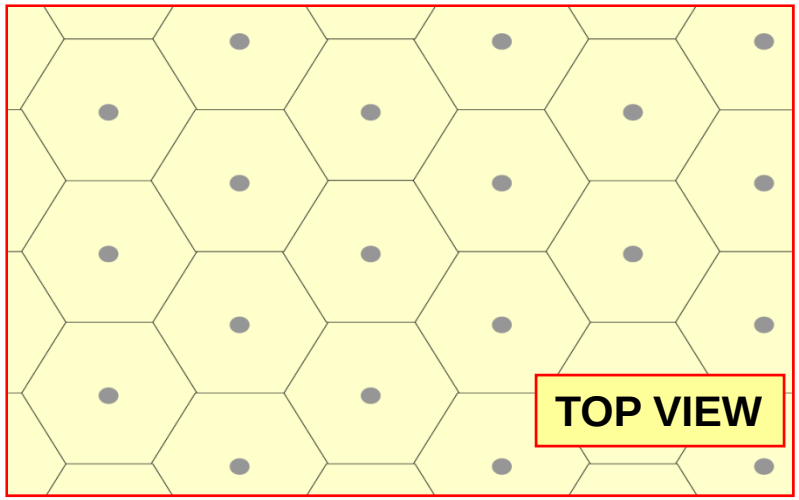


photocathode



"LIGHT AMPLIFIER"



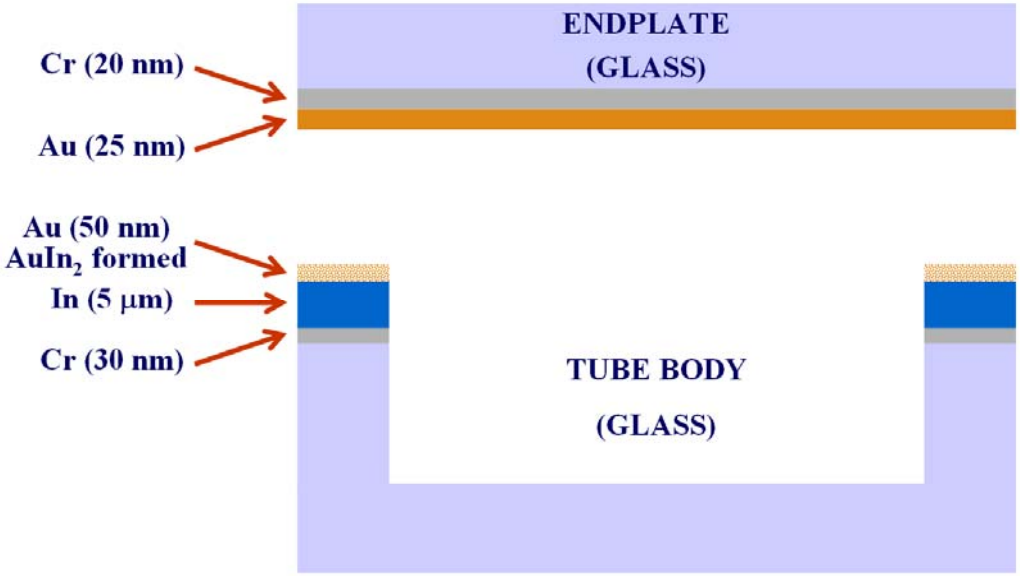


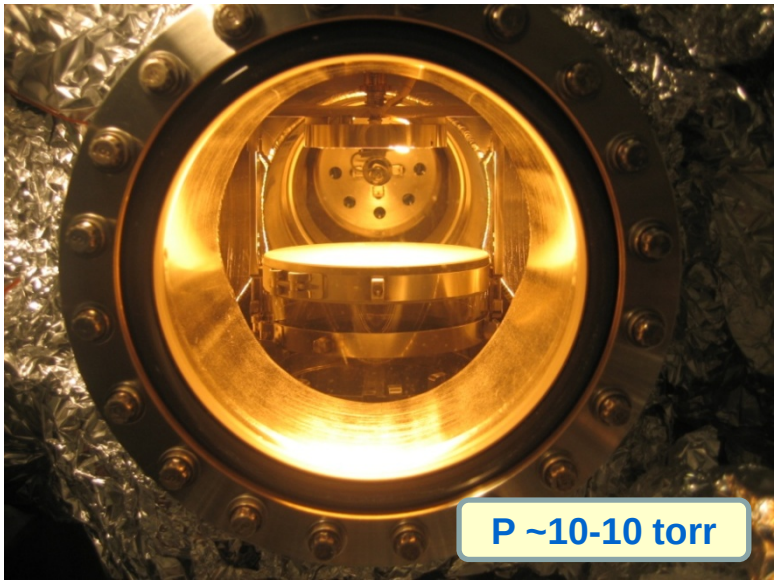
←Ferenc / Lorenz
NIMA 567(2006)166

New Oxide-Free Thin-Film Indium Sealing Method

@ LOW-TEMPERAURE

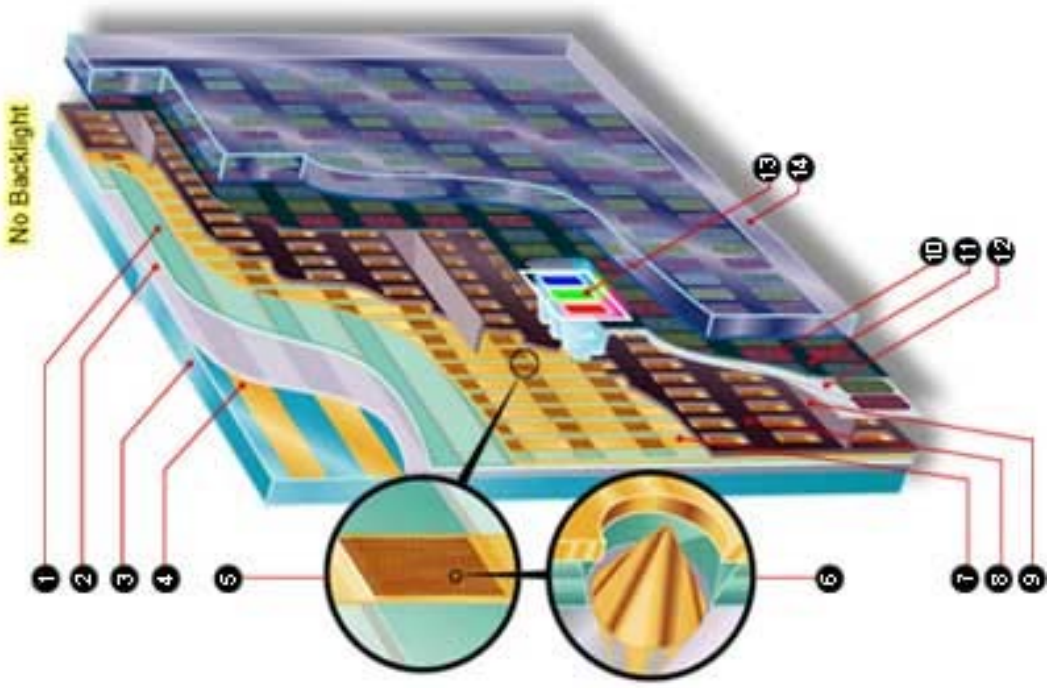
GLASS-TO-GLASS

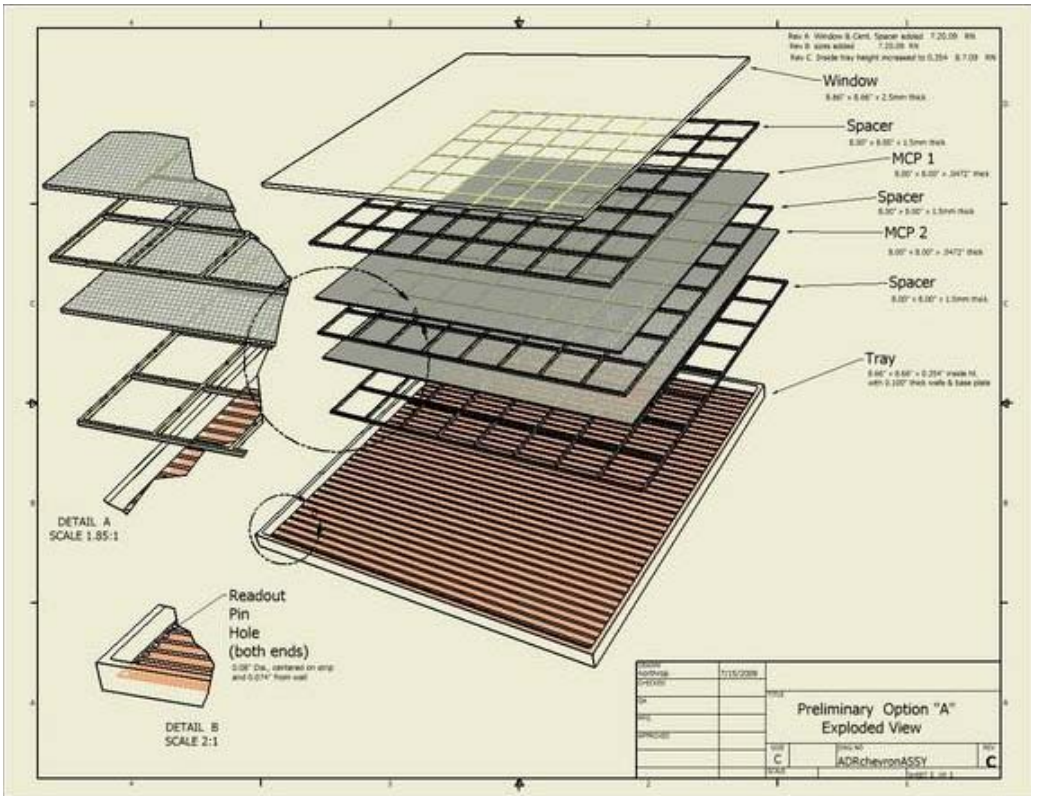




Daniel Ferenc, Andrew Chang, Leah Johnson, Daniel Kranich, Alvin Laille and Eckart Lorenz. A New Method for Vacuum Sealing of Flat-Panel Photosensors.

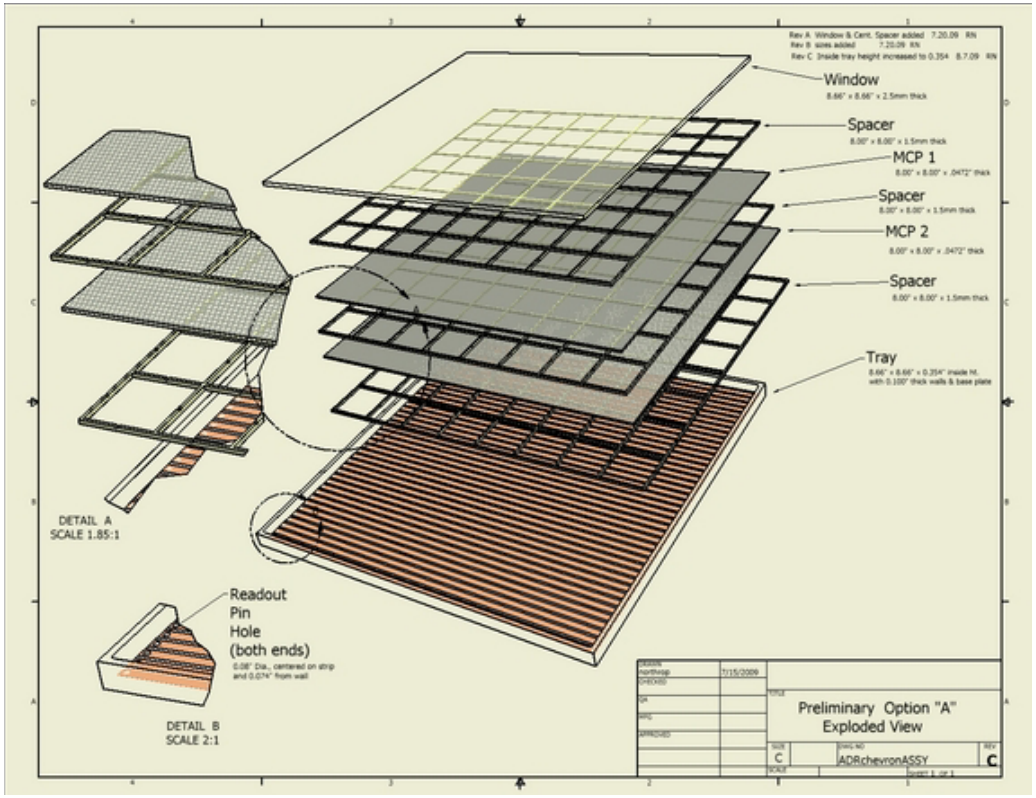
NIM-A567(2006)205-208 (→ see ref. by Milun et al.)


No Backlight


Window
Spacer
MCP 1
Spacer
MCP 2
Spacer
Tray
DETAIL A
SCALE 1.85:1
Readout
Pin
Hole
(both ends)
DETAIL B
SCALE 2:1
Preliminary Option "A"
Exploded View
ADRchevronASSY

Large Area, flat, vacuum MCP-Photon detectors

The Large Area Picosecond Photodetector (LAPPD) Collaboration



Search for economic methods for large-area MCPs

6 sq-m area in a 8”x8” panel, low gas conductance

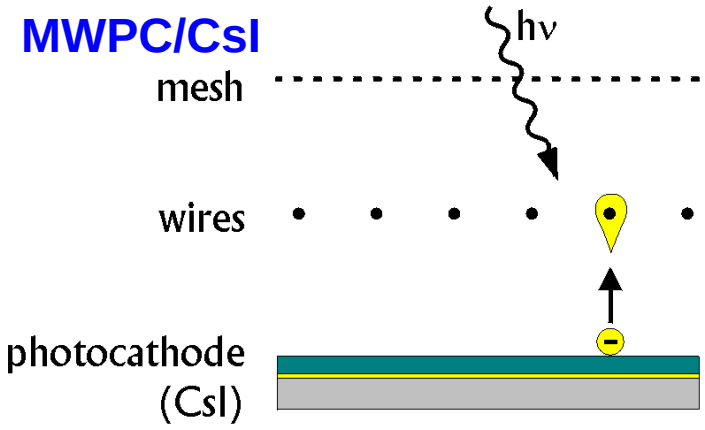
- **funded) by DOE and NSF**
- **4 National Labs**
- **3 US small companies;**

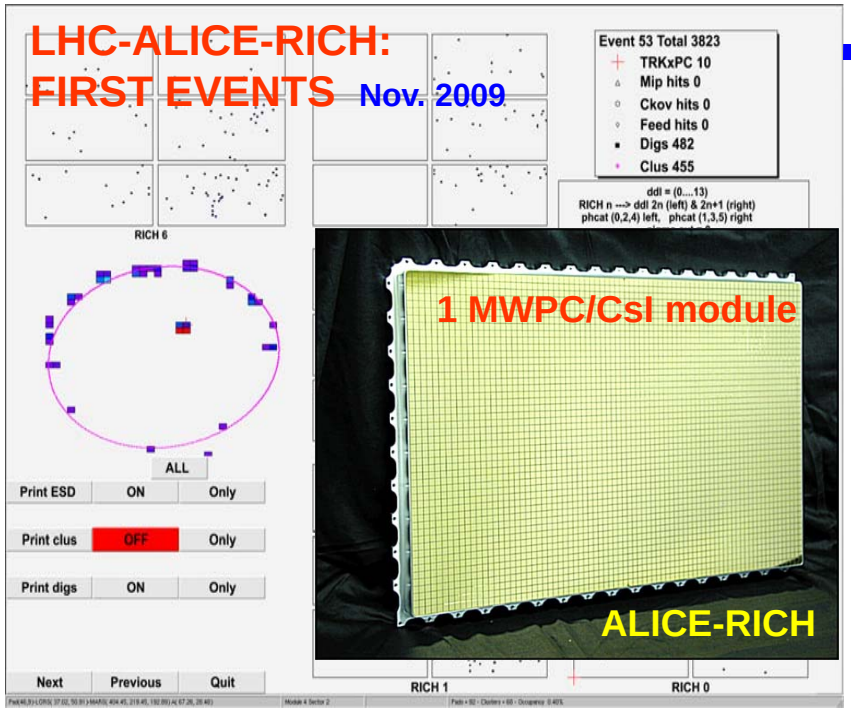
Lead by Henry Frisch, University of Chicago

Flat-panel Gaseous Photosenosors

Taken from Amos Breskin's talk at Vienna 2010

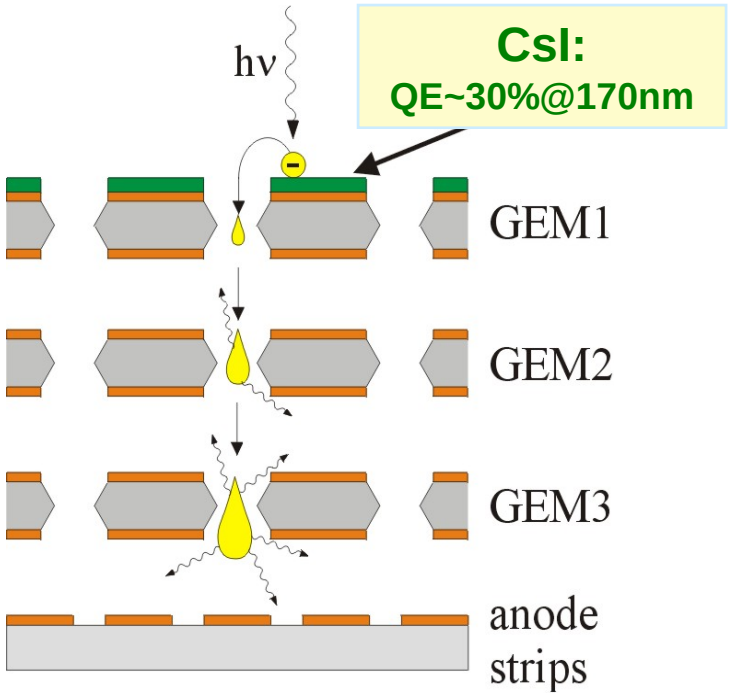
Large-area Flat Gas-Photomultipliers GPM





NEW: cascaded-GEM GPMs

A.B. et al, Weizmann



UV: CsI photocathode

Gain: >10^6

Single-photon sensitivity

100 micron resolution

OK in high $\vec{B}$

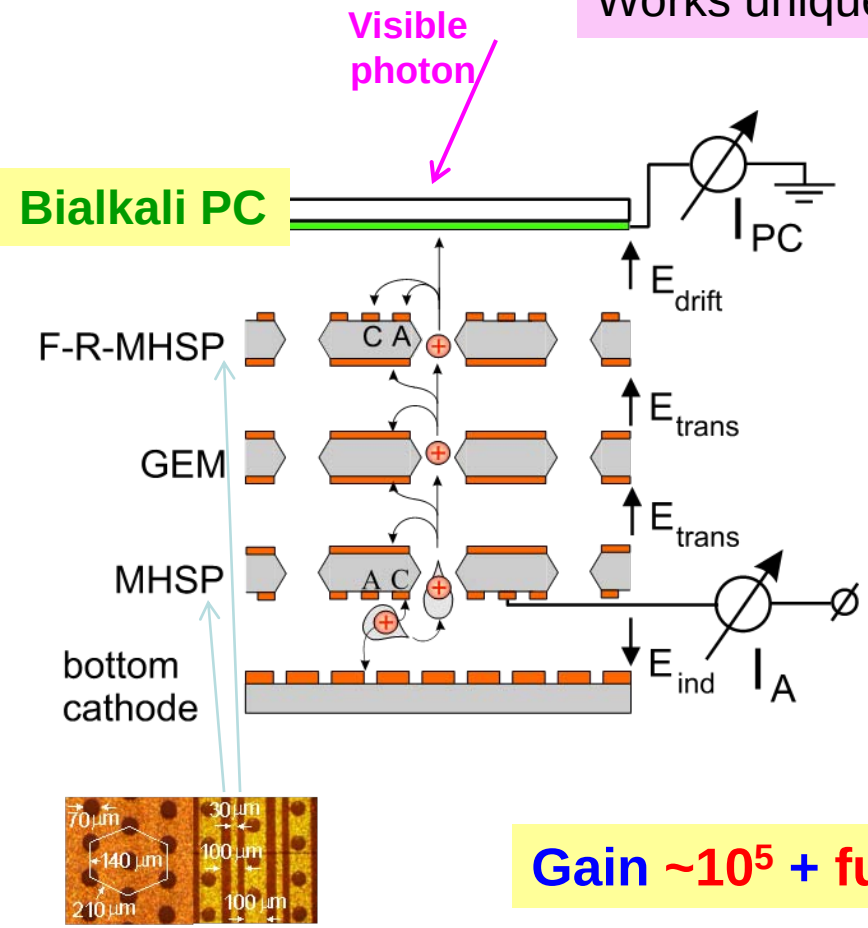
Amos Breskin – Vienna 2010

Main application: RICH

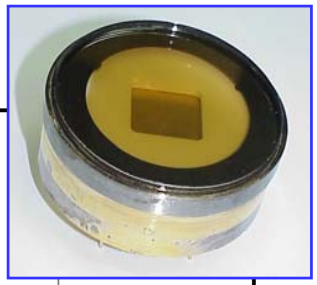
CHALLENGE: visible-light Gas Photomultipliers!

Cascaded patterned hole-multipliers with K-Cs-Sb photocathodes

Works uniquely due to efficient ion blocking



Sealed vis-GPM



Cascaded GEM: gain limit was <100

Gain ~10^5 + full photoelectron collection efficiency

➔"flat-panel" large-area photon-imaging detectors insensitive to $\vec{B}$
➔ numerous applications: RICH, large Astro experiments…

Lyashenko 2009 *JINST* 4 P07005

HPDs

HYBRID PHOTON DETECTORS

A VERY LARGE AND DIVERSE GROUP

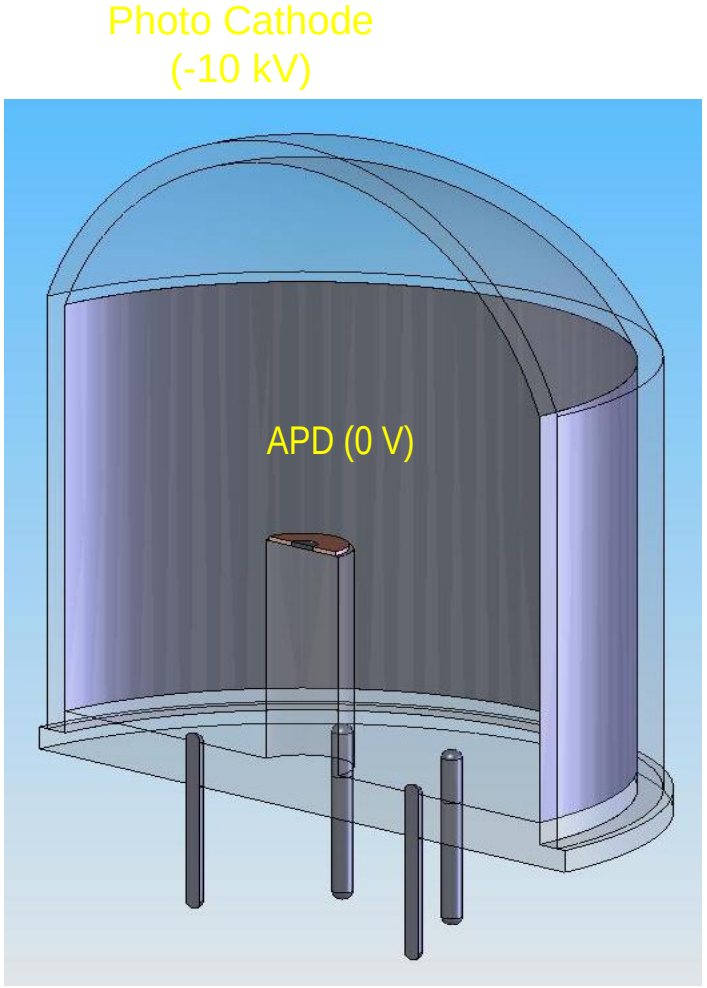
(DYNODES → SILICON DETECTOR)

TOM YPSILANTIS et al.,
AQUARICH CONCEPT (also development for LHCb)

VERY FAR FROM BEING 'MINIMALISTIC'

D.F., Imaging Hybrid Photon Detectors with Minimized Dead Area and Protection Against Positive Ion Feedback. Nuclear Instruments and Methods in Physics Research A431(1999)460-475.

QUPID HPD - Katsushi Arisaka + Hamamatsu
(Quartz Photon Intensifying Detector)

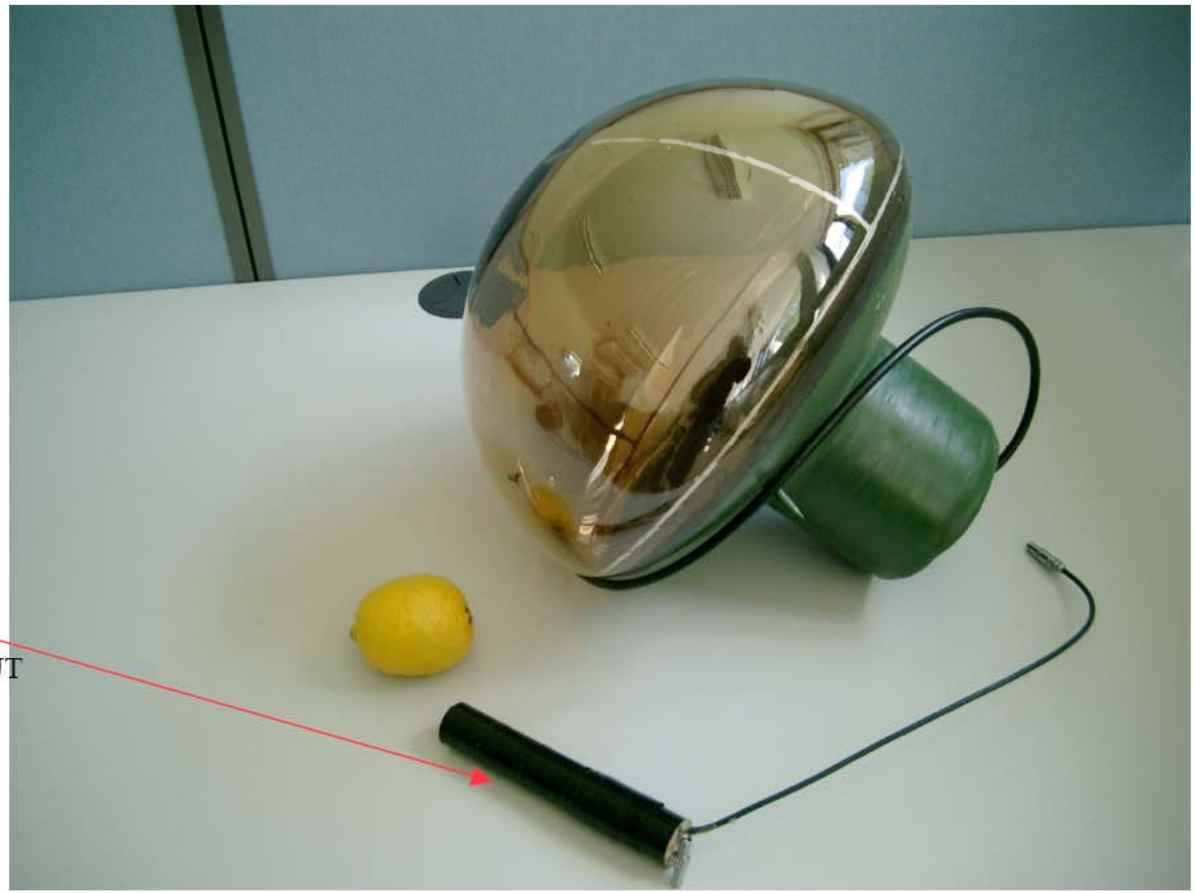


THE QUASAR

IMPROVED VERSION OF THE SMART PMT
- LARGE ACTIVE AREA/TOTAL VOLUME
- SYMMETRIC PHOTOELECTRON COLLECTION
- PRACTICALLY 100%PHOTOELECTRON COLL.EFFICIENCY
- NO NEED FOR BLEEDER CURRENT -> VERY LOW HT POWER
- ALREADY IN LONGTERM USE IN LAKE BAIKAL
- RELATIVELY CHEAP
- CAN DETECT SINGLE PHOTOELECTRONS,
- F-FACTOR ≈1.3

- CRYSTAL WITH LONG DECAY TIME
- RELATIVELY LOW LIGHT YEALD
- PRODUCTION STOPPED

THE FOLLOWING TESTS HAVE BEEN CARRIED OUT WITH A QUASAR



→ Geiger-Mode APD?

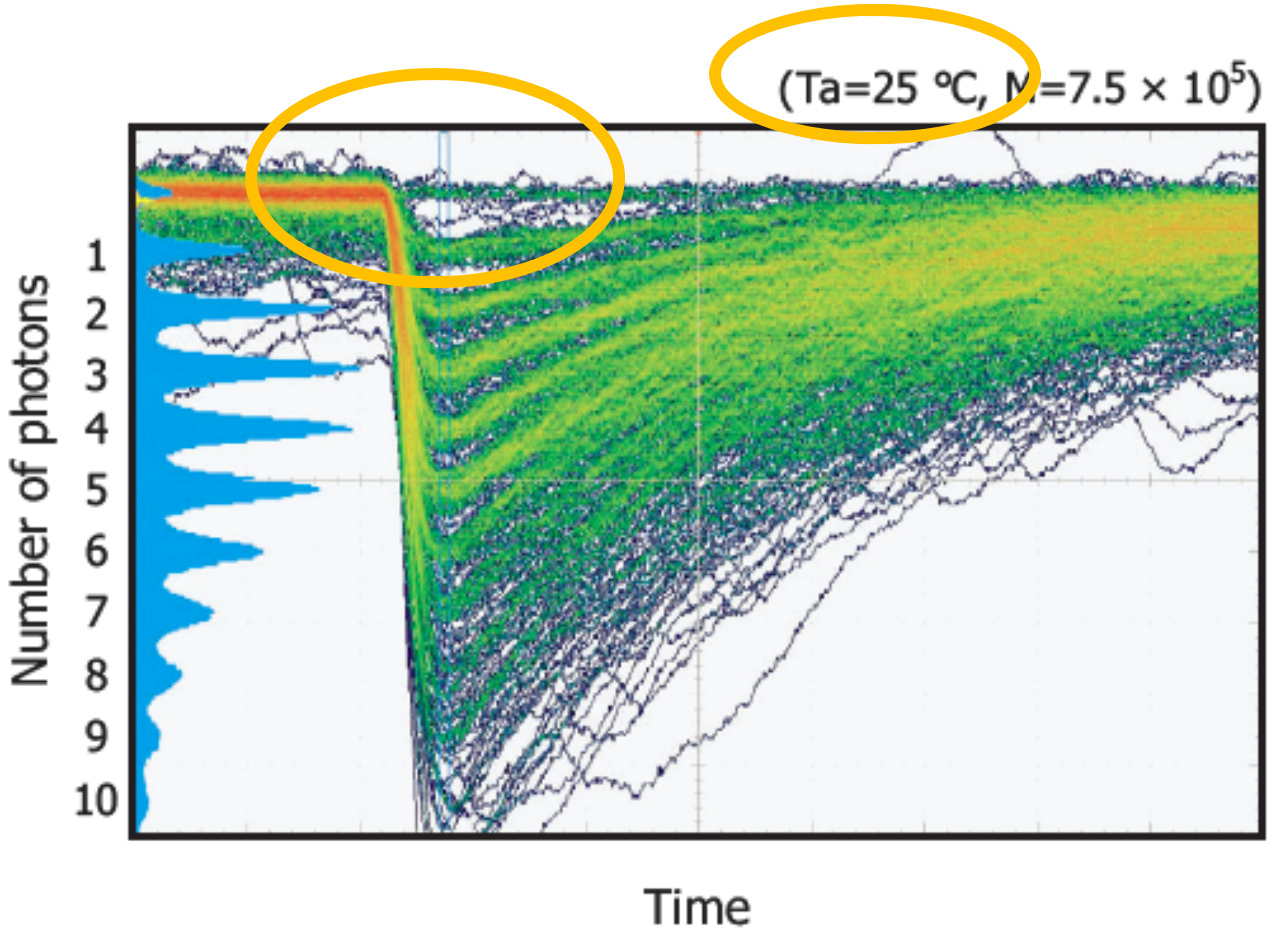
‘LIGHT AMPLIFIER’
(light in light out)

BETTER:

LIGHT CONCENTRATOR

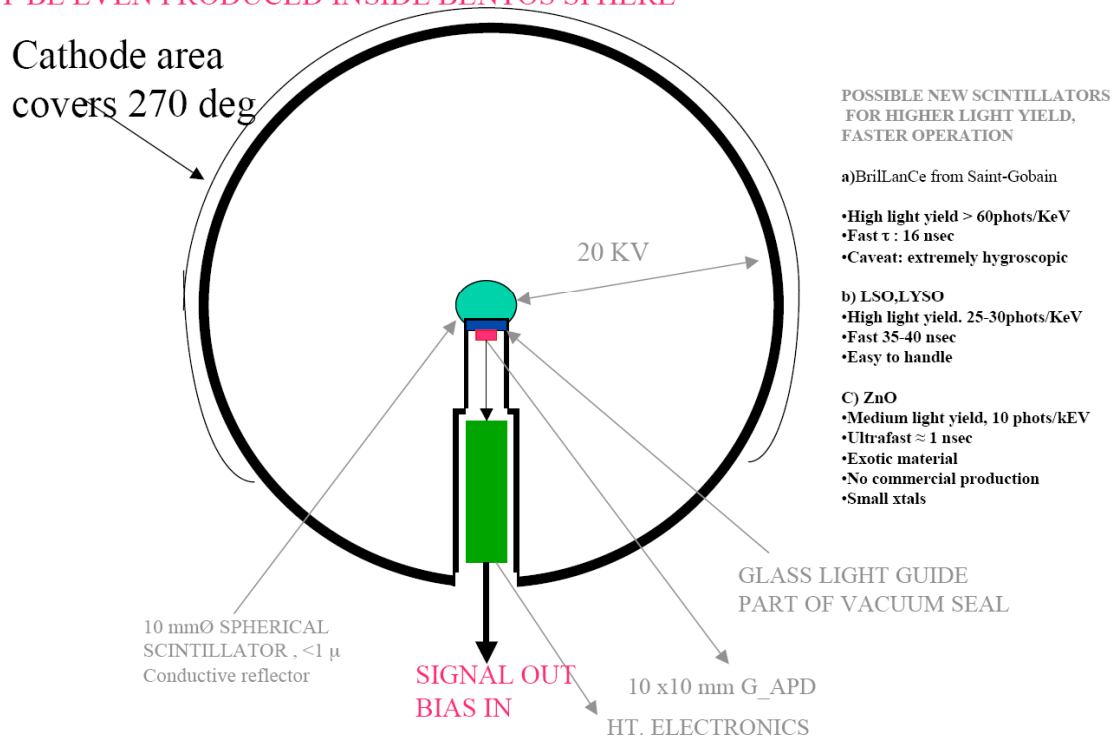
PROBLEM with G-APDs
1-photon signal ~ noise

Pulse waveform (S10362-33-050C) when using an amplifier (120 times)



LIGHT AMPLIFIER
OR BETTER – LIGHT CONCENTRATOR

A SPHERICAL SOLUTION WITH SPHERICAL SCINTILLATOR, SIMPLE PRODUCTION
5 STERAD, MINIMAL TIME JITTER, ELECTRONICS CAN BE LOCATED IN STEM
MAY BE EVEN PRODUCED INSIDE BENTOS SPHERE



POSSIBLE NEW SCINTILLATORS
FOR HIGHER LIGHT YIELD,
FASTER OPERATION

a)BrilLanCe from Saint-Gobain

- **High light yield > 60phots/KeV**
- **Fast τ : 16 nsec**
- **Caveat: extremely hygroscopic**

b) LSO,LYSO
- **High light yield. 25-30phots/KeV**
- **Fast 35-40 nsec**
- **Easy to handle**

C) ZnO
- **Medium light yield, 10 phots/kEV**
- **Ultrafast ≈ 1 nsec**
- **Exotic material**
- **No commercial production**
- **Small xtals**

- D. Ferenc, D. Kranich, A. Laille, E. Lorenz, “The Novel Light Amplifier Concept,” Nuclear Instruments and Methods in Physics Research A567(2006)166-171.
- E. Lorenz and D. Ferenc, “A new Readout of large area Smart Photomultipliers by Geiger-mode APDs,” Nuclear Instruments and Methods in Physics Research A572(2007)434-436.

LIGHT AMPLIFIER → OUT OF THE (G-APD) BUSHES!

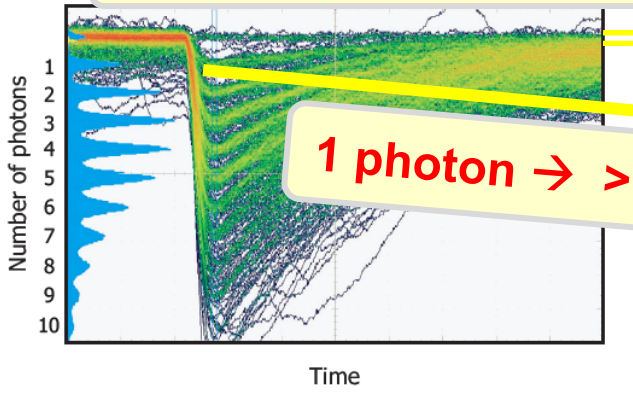
(1 photoelectron SIGNAL >> NOISE)

DIRECTLY HIT G-APD

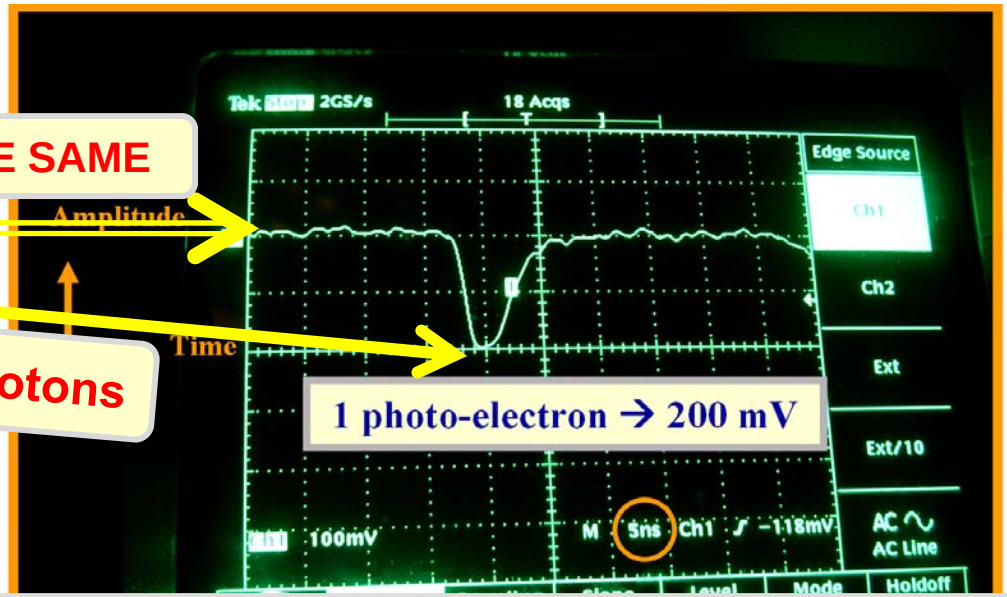
LIGHT AMPLIFIER

Pulse waveform (S10362-33-050C) when using an amplifier (120 times)

INTRINSIC G-APD NOISE = THE SAME



1 photon → >10 photons



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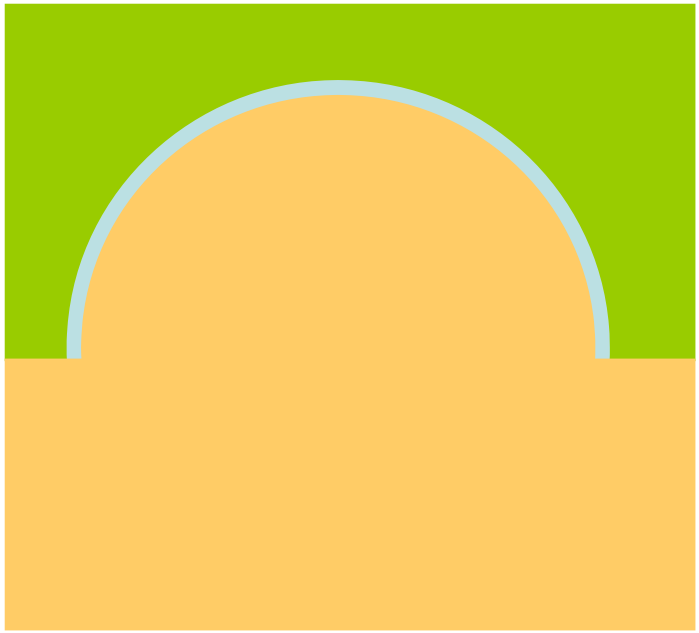
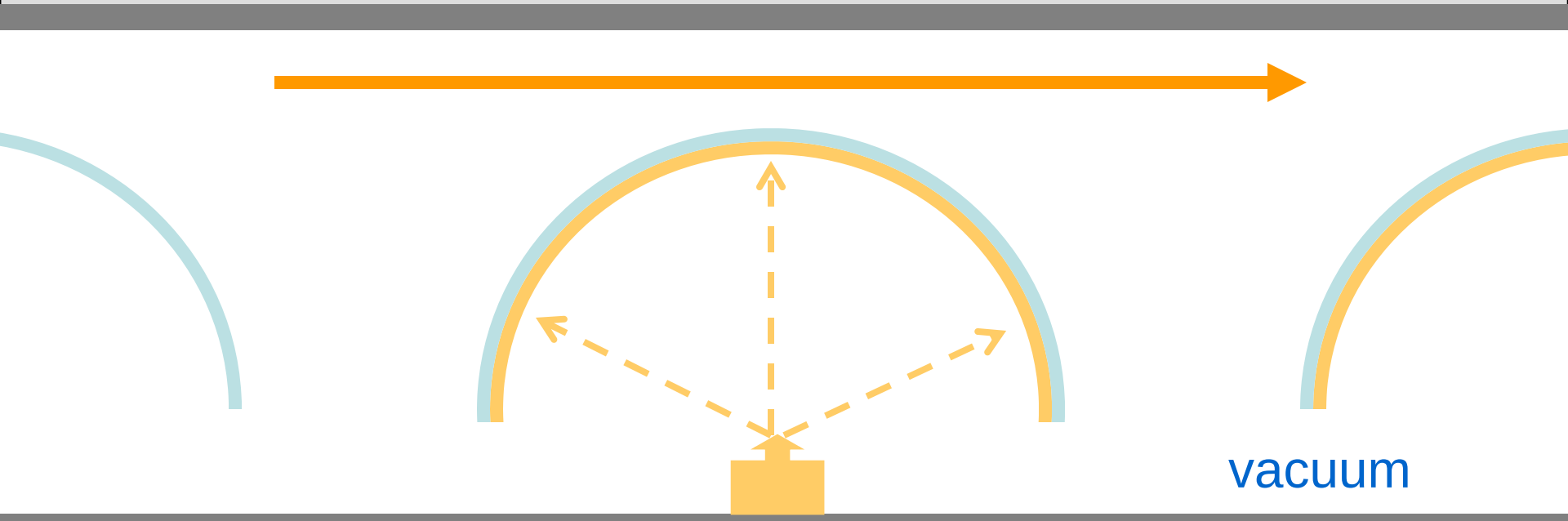
E. Lorenz and D. Ferenc, "A new Readout of large area Smart Photomultipliers by Geiger-mode APDs," Nuclear Instruments and Methods in Physics Research A572(2007)434-436.

Others…





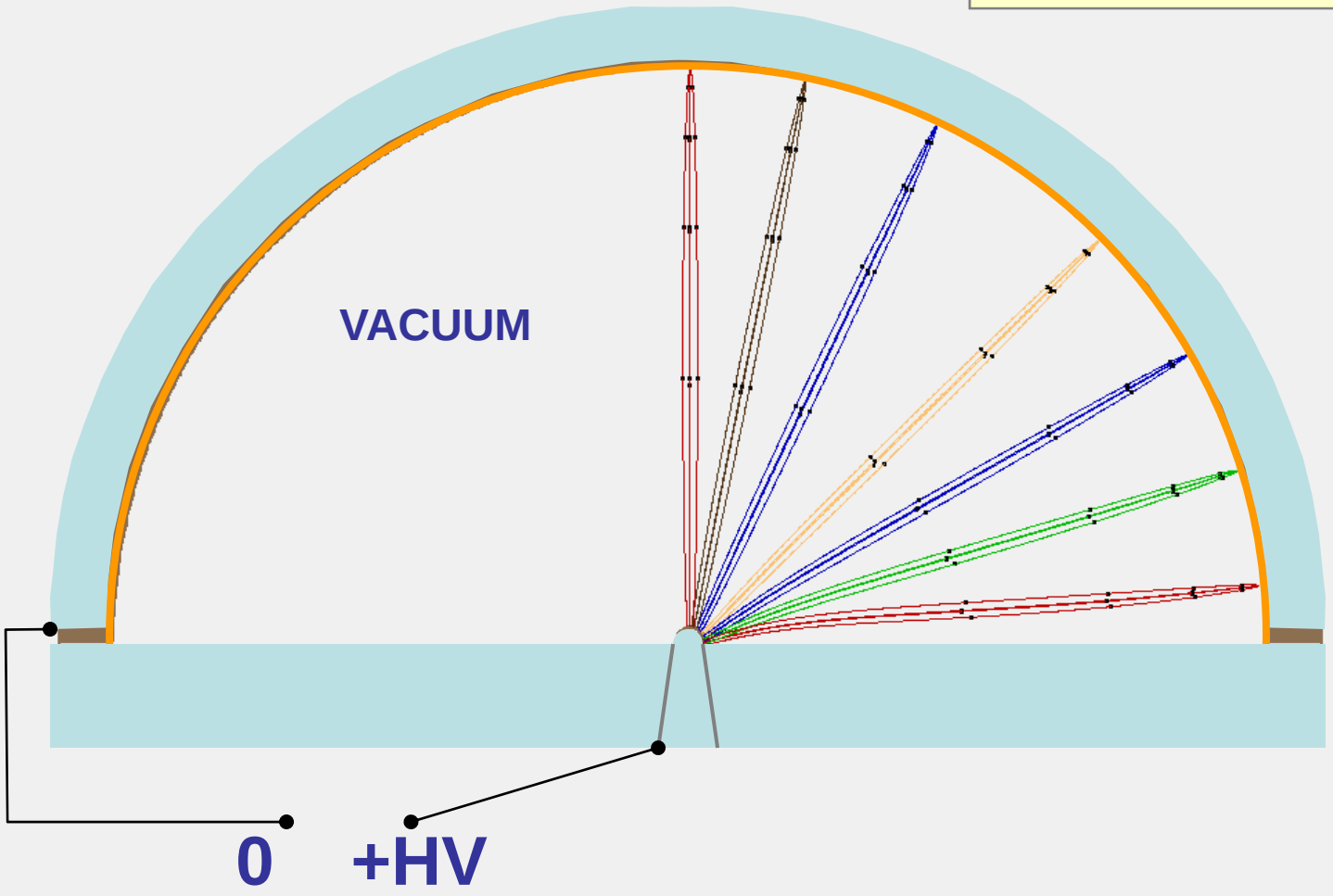
PRODUCTION LINE - VACUUM

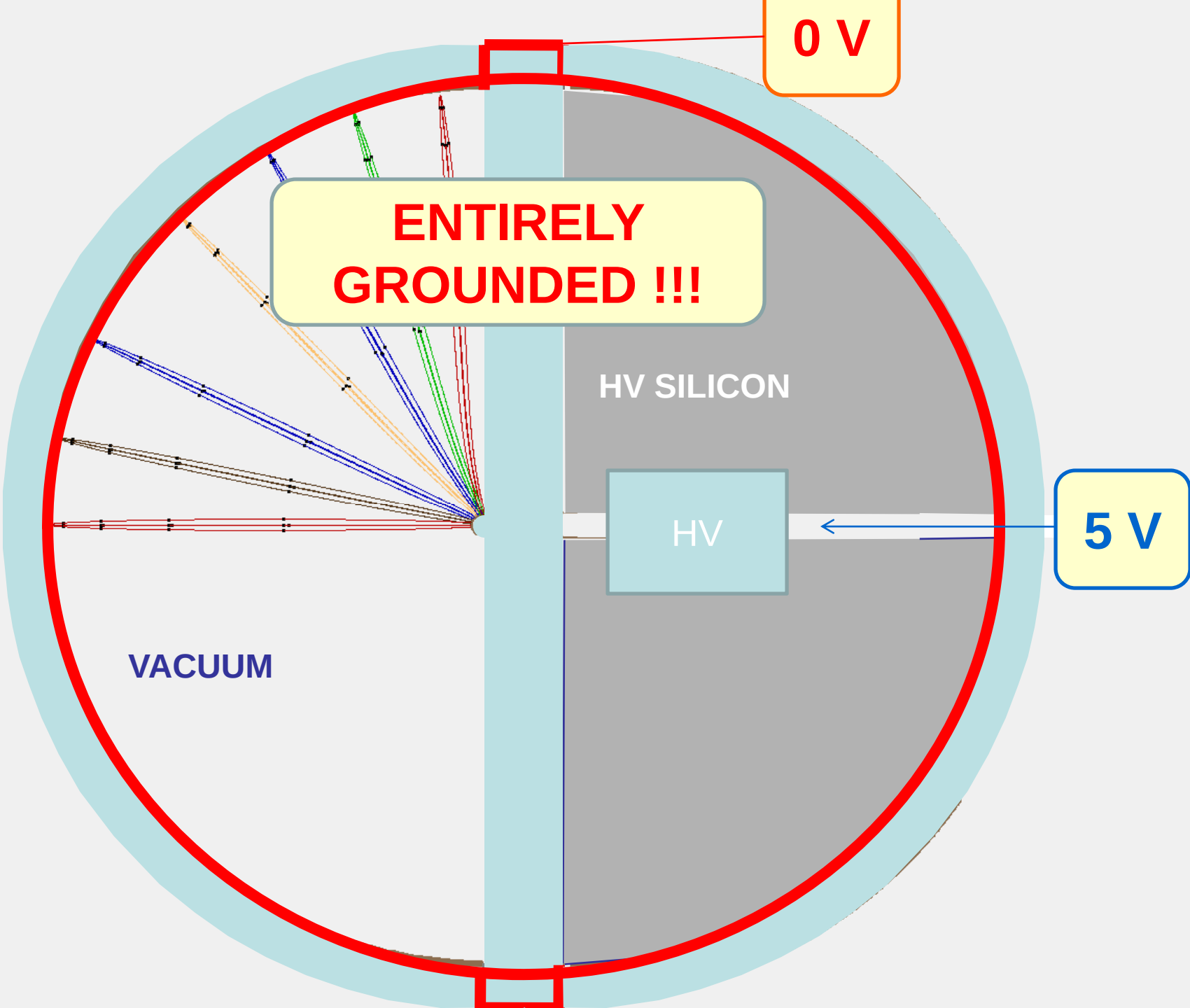
OPEN ARCHITECTURE

ABALONE

Cr-In-Au Vacuum Seals
=
Voltage Feedthroughs

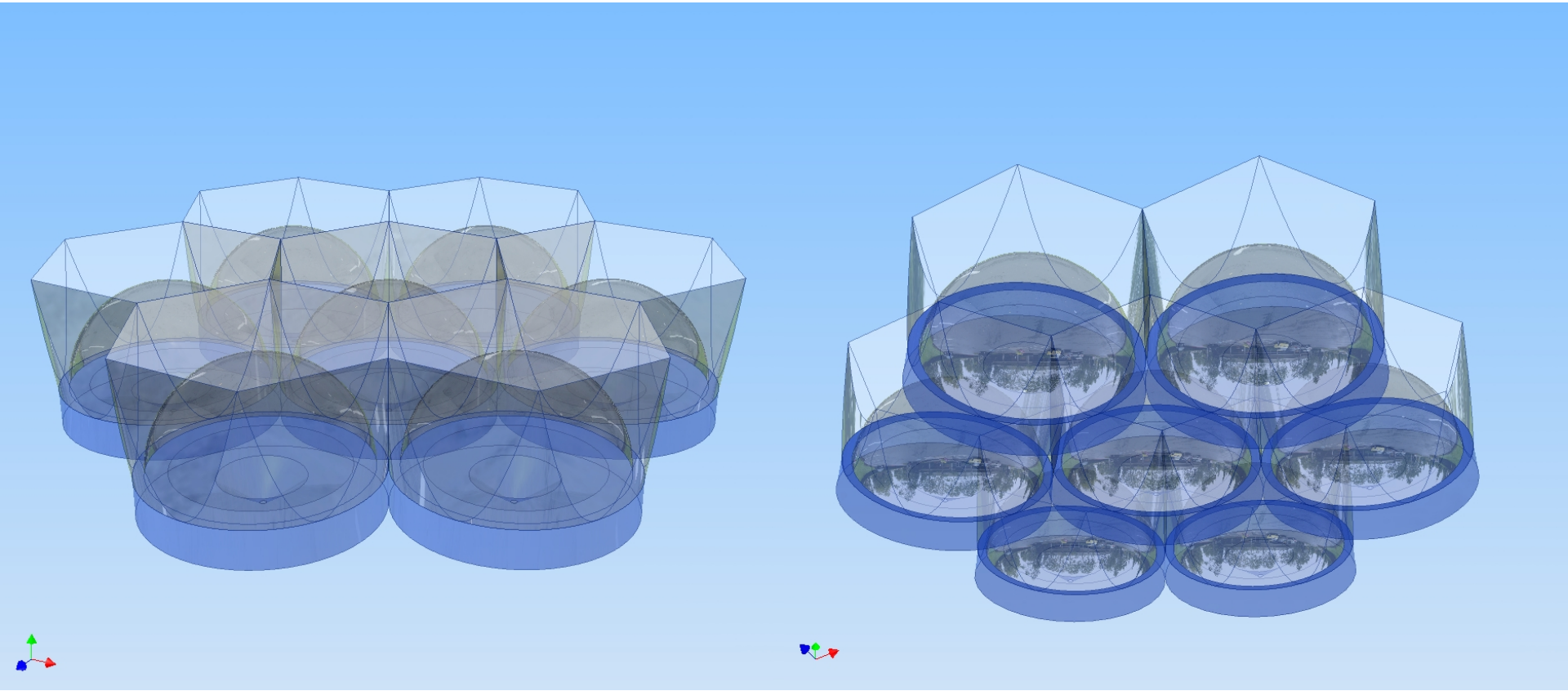
- → 5-inch diameter
- → 20 kV
- → 45 deg. angular spread
- → 0.25 eV initial electron energy



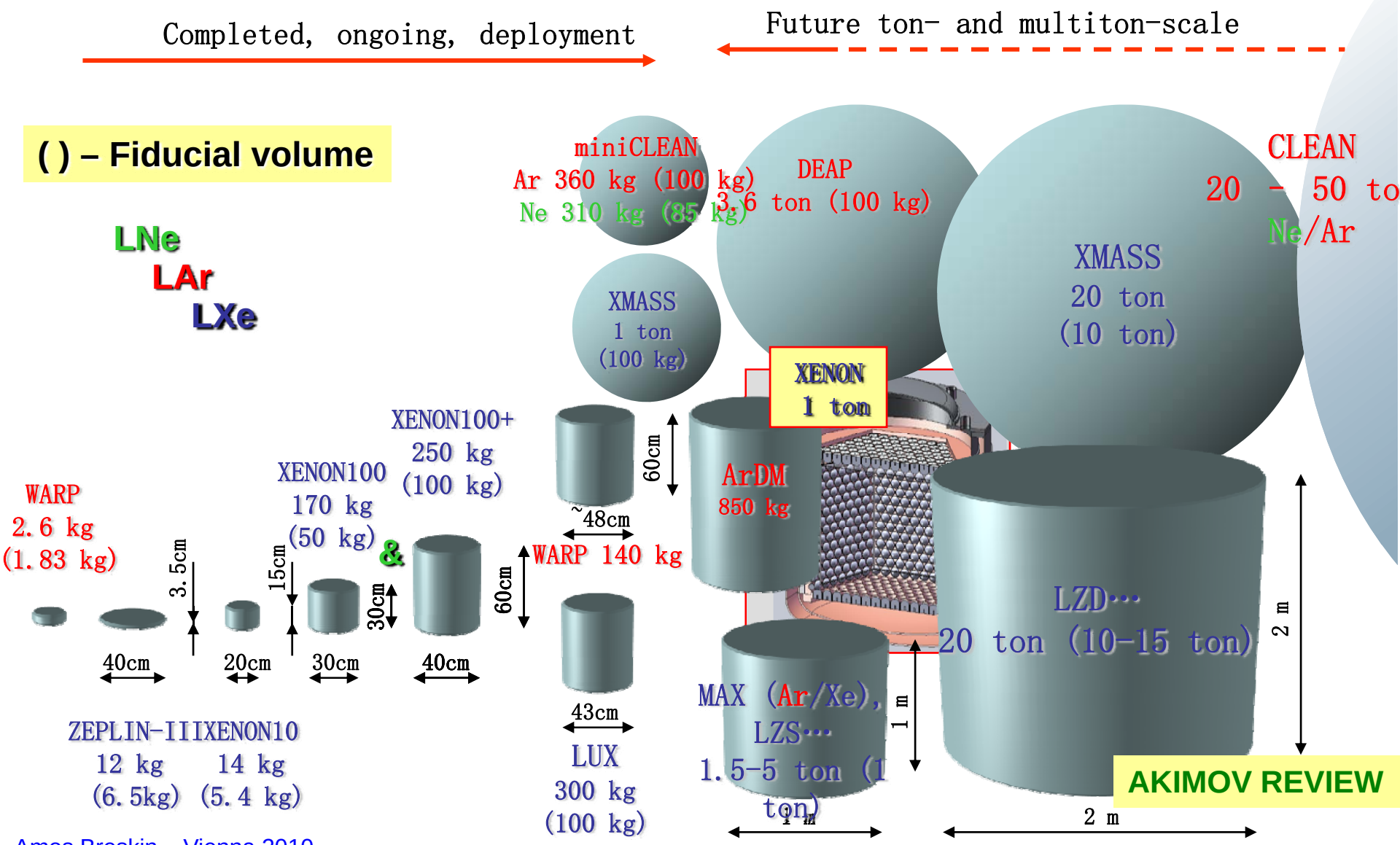

0 V
ENTIRELY
GROUNDED !!!
HV SILICON
HV
5 V
VACUUM

BACK TO A FLAT PANEL PHOTOSENSOR WITH ~ZERO DEAD AREA

→ARRAYS OF open, moldable ABALONE “hex-hemispheres”



MANY NOBLE-LIQ DARK MATTER DETECTORS
NEED RADIO-CLEAN PMT!



SUMMARY

THE FUTURE ASTROPARTICLE PROJECTS WILL BECOME A GREAT PLAYGROUND ONLY WHEN WE SOLVE FUNDAMENTAL DETECTOR (MASS-PRODUCTION) PROBLEMS

CONCEPTUALLY, ON THE RIGHT TRACK ALREADY, BUT WE NEED TO PUT SIGNIFICANTLY MORE EFFORT (TOGETHER WITH THE INDUSTRY), AND ALSO CONSIDER 'REAL' MARKETS (medical imaging and nuclear nonproliferation)

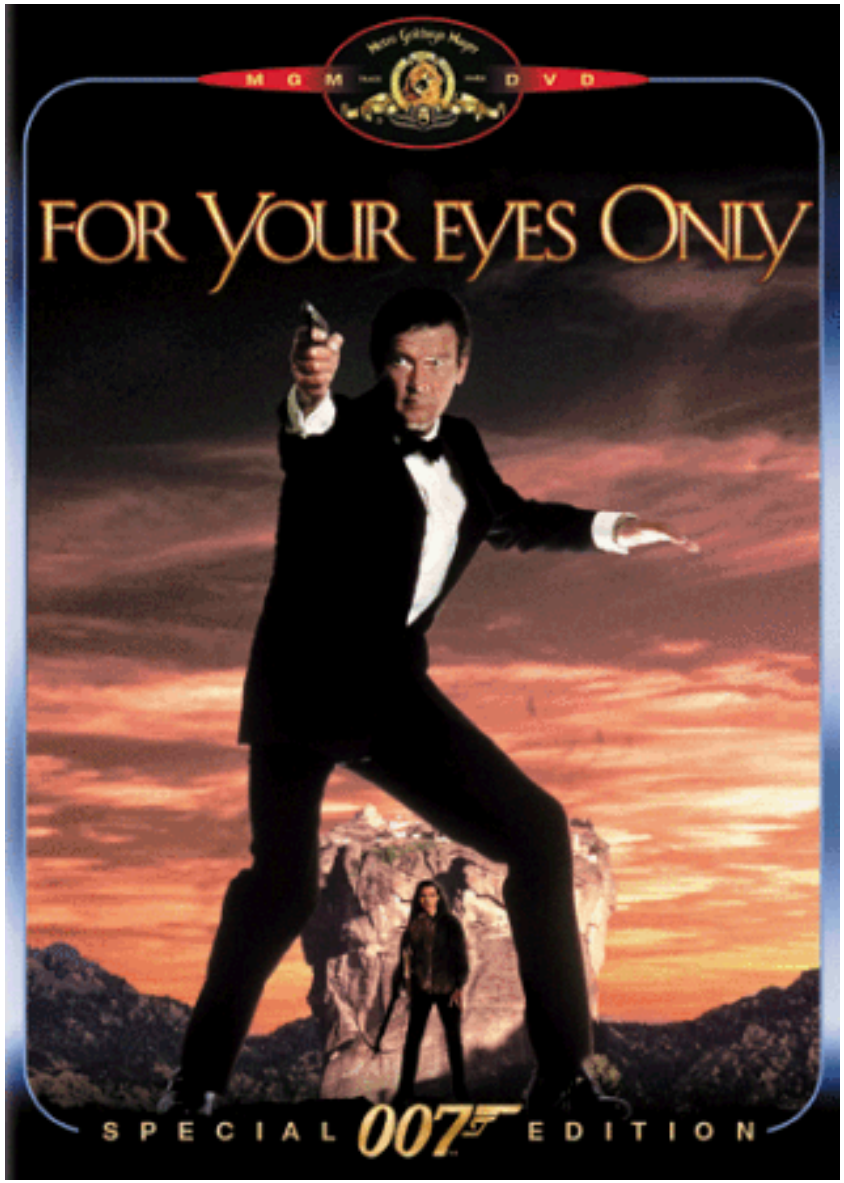
→ ELEGANT SOLUTIONS, BUT VERY LARGE INVESTMENT:

- **MONOLITHIC FLAT-PANEL MICROPATTERNED VACUUM DETECTORS (MCP,…?)**
- **MONOLITHIC FLAT-PANEL MICROPATTERNED GASEOUS DETECTORS (GEM, MICROMEGAS,…?)**
- **MONOLITHIC FLAT-PANEL MACROSCOPIC CELL VACUUM DETECTORS (ReFerence)**

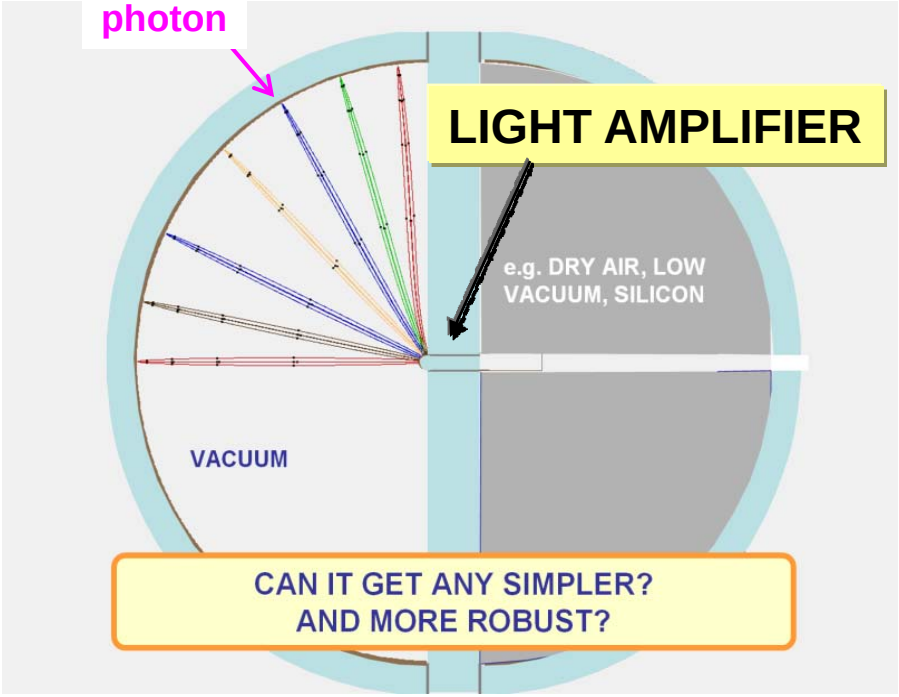
→ SCALLABLE, AND MORE AFFORDABLE APPROACH:

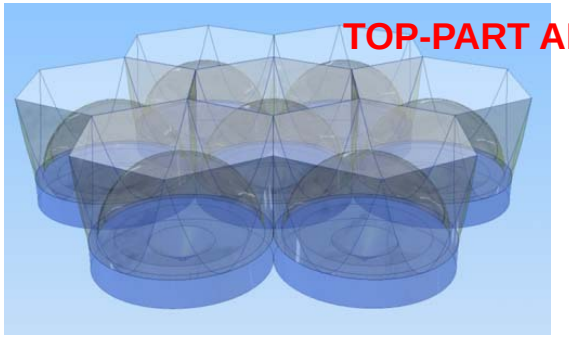
(PROBABLY REALISTIC RIGHT NOW!!!)

- **FLAT-PANEL DETECTORS BUILT OF INDIVUDUAL PIXELS**
- **(HEMI)SPHERICAL 'LIGHT AMPLIFIERS', LARGE AND SMALL ('QUASAR-2', ABALONE,…?)**



ABALONE

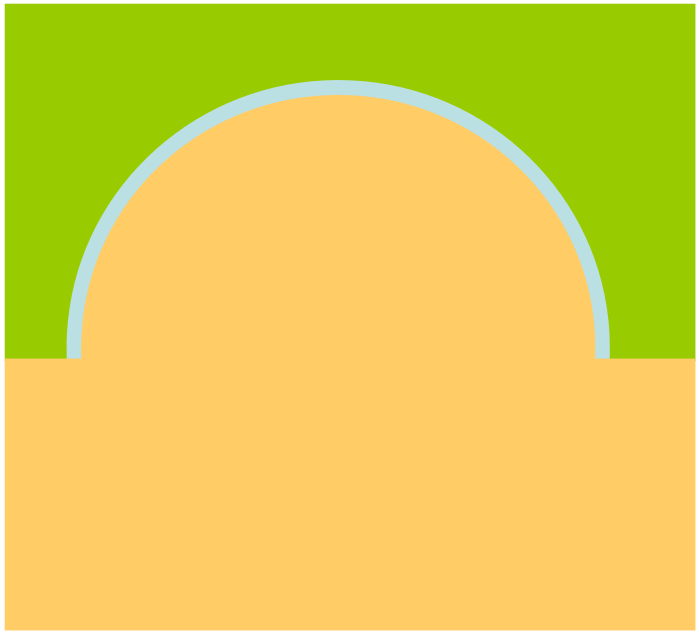




Daniel Ferenc, Patent pending

ABALONE

MASS PRODUCTION - GLASS MOLDING



MASS PRODUCTION - GLASS MOLDING