

ASTROPARTICLE PHYSICS

**TOWARDS BRIGHT FUTURE
WITH INNOVATIONS**

Daniel Ferenc

**University of California Davis
Sabbatical @ FESB, University of Split, Croatia**

A VERY EXCITING PLAYGROUND

- MANY EXISTING EXPERIMENTS (FANCY NAMES)**
- MANY RESULTS AND DISCOVERIES**
- MANY COLLABORATORS AND AGENCIES**
- GREAT POTENTIAL –
MANY NEXT-GENERATION PROJECTS
PROPOSED**
- PROBLEMS: DREAMS vs. REALITY**

**MY FOCUS → ON THE KEY PROBLEM
AND THE SOLUTIONS**

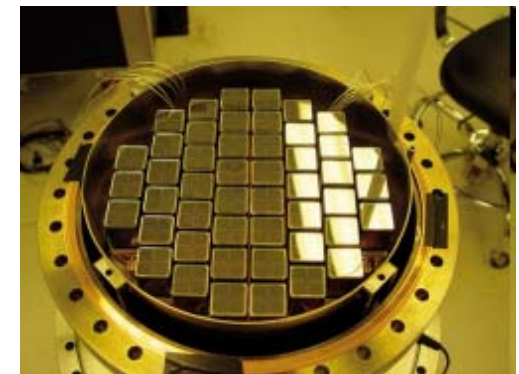
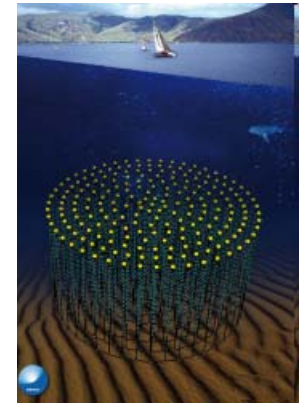
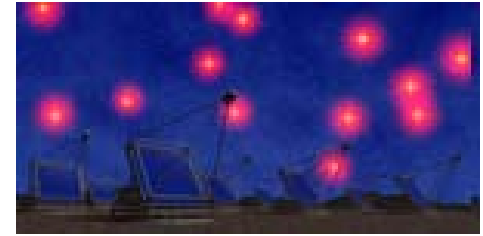
**FUTURE
ASTROPARTICLE PROJECTS
WILL BECOME
A REALLY GREAT PLAYGROUND
ONLY IF WE SOLVE
FUNDAMENTAL DETECTION
PROBLEMS**

**WE ARE ON THE RIGHT TRACK ALREADY
BUT IT SEEMS THAT
WE
NEED TO INITIATE THE FORMATION OF
NEW COMPANIES
WITH THE HELP OF ????**

**IT IS MANDATORY TO CONSIDER REAL MARKETS
→ MEDICAL IMAGING
→ NUCLEARNONPROLIFERATION**

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

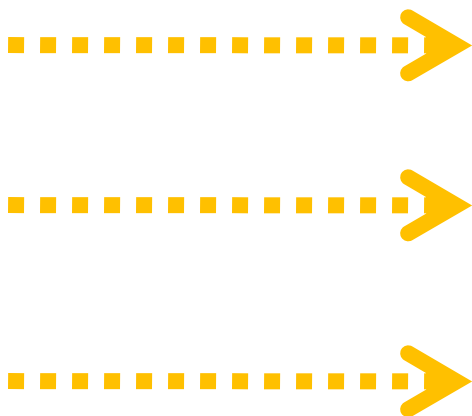


Luminosity

LHC

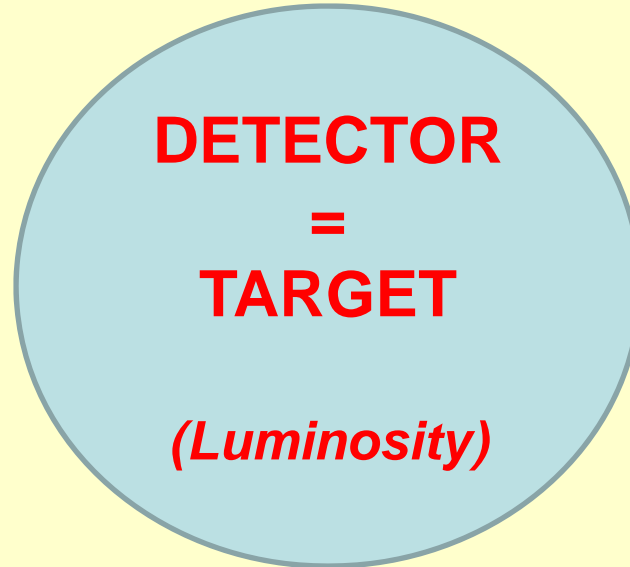


ASTROPARTICLE



DETECTOR
=
TARGET

2 FUNDAMENTAL PROBLEMS WITH



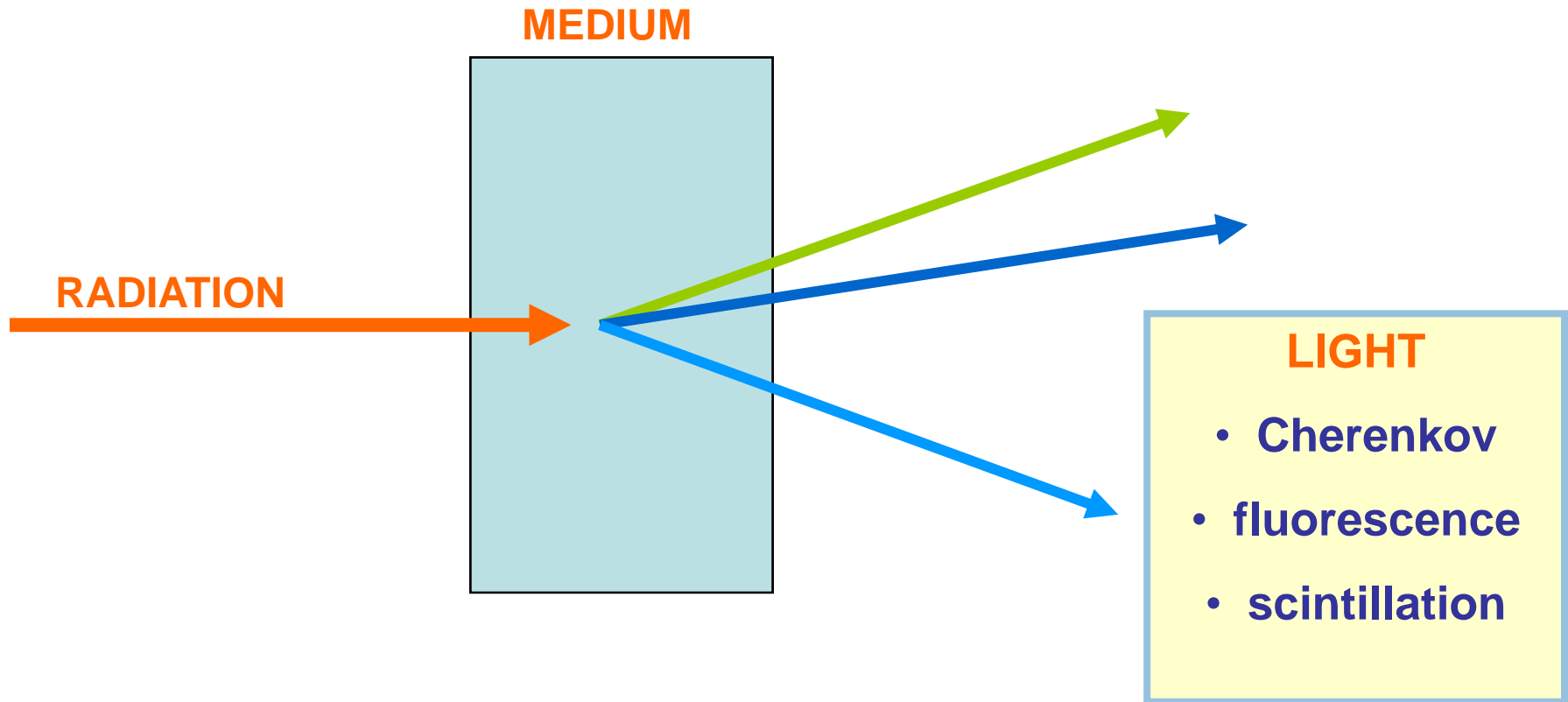
1. THE NEEDED SIZE

→ Only remaining materials = the atmosphere, water, ice, mineral oil, LN₂, LXe

2. A BAD GUY – Mr. Liouville:

he makes **photon detection** difficult and expensive

PHOTON DETECTION – KEY TECHNOLOGY (AND KEY PROBLEM)



**RARELY OCCURRING PHENOMENA → SUPER-LARGE DETECTORS
→**

ONLY NATURAL TRANSPARENT MEDIA ARE POSSIBLE

Water, Ice, Atmosphere, Mineral Oil

**FUNDAMENTAL, GROUNDBREAKING INSTRUMENT
DEVELOPMENTS AND INVENTIONS
SOMETIMES BECOME RECOGNIZED**

**The Nobel Prize in Physics 2010
for Selotape/Scotch Tape → peeling off carbon layers...**

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

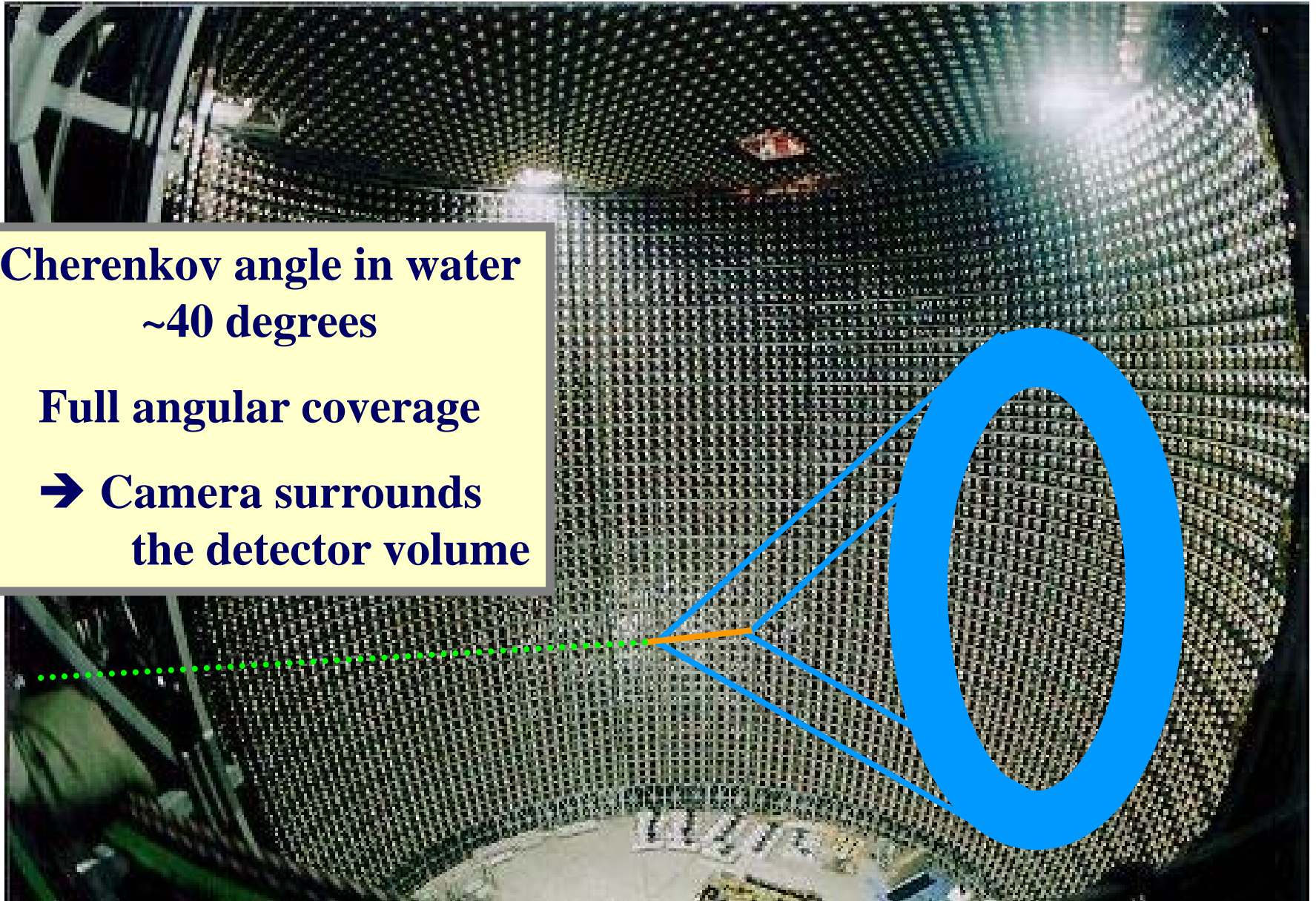
GEORGES CHAPACK

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

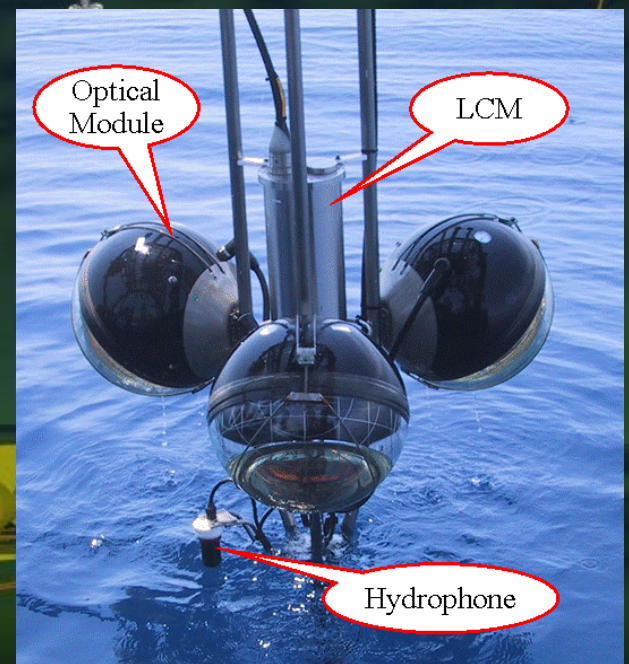
→ HAND-MADE COMPONENTS

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



ANTARES, under-water detector

885 10" PMTs



Hallewell

LARGE VOLUME RARE-EVENT EXPERIMENTS

SK Φ 500mm Vac. PMT



ALL PRODUCERS OF LARGE PMTs
(except Hamamatsu)
VANISHED!

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

Fermilab Long Baseline Neutrino Experiment LBNE

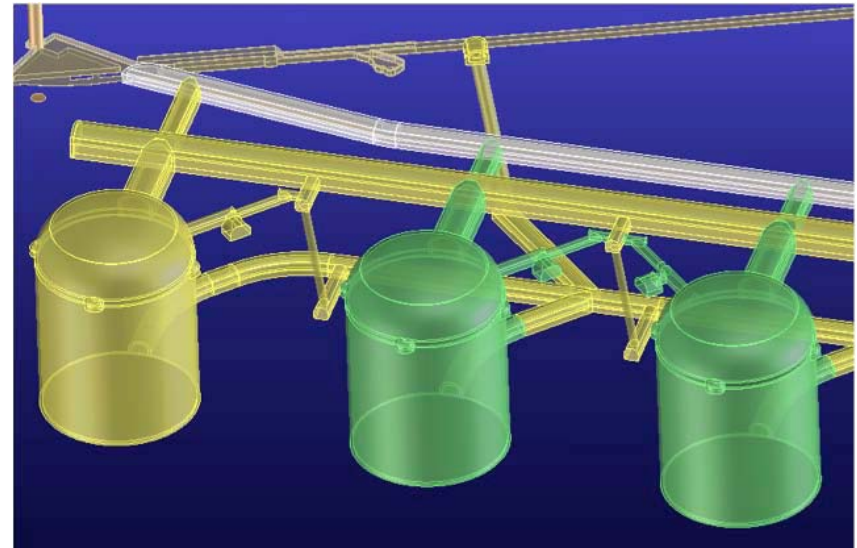
~15,000 PMTs



HYPER-K, LENA... > 100,000 PMTs!



Super-K



300,000 m³ WATER + PMTs
12,000 m² 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**

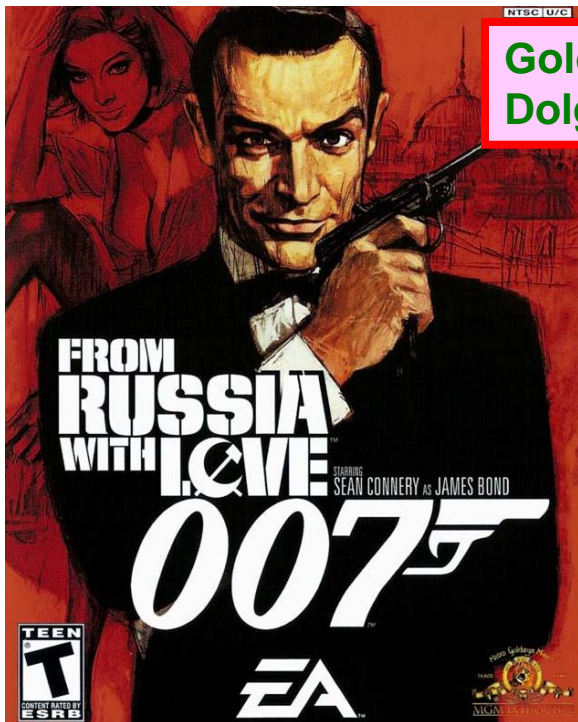
→ Camera can have a **small area**



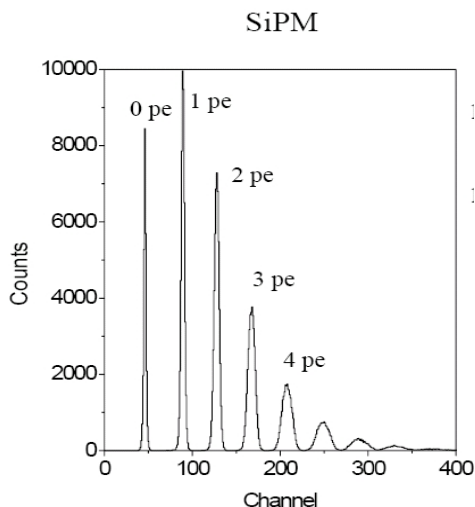
MAGIC Telescope Inauguration, October 10 2003. (Photo-W. Ko)

Geiger-mode Avalanche Photodiodes

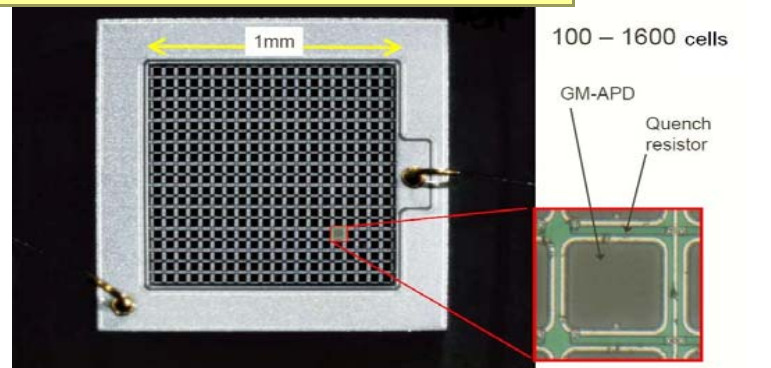
MRS APD, MAPD, SiPM, MPPC, SSPM, SPM, DAPD, PPD ...



Golovin, Sadygov,
Dolgoshein...



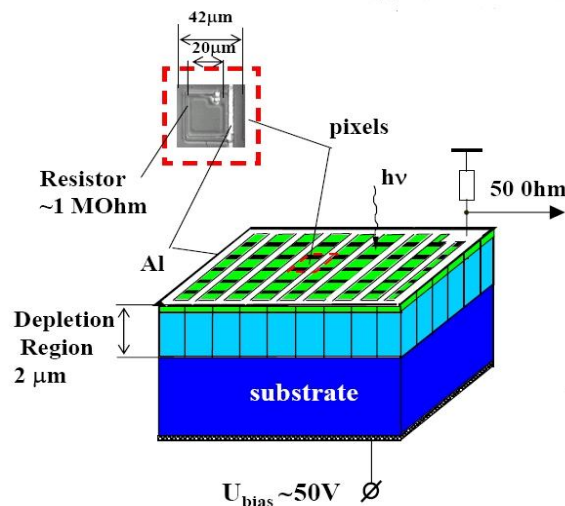
MANY PRODUCERS!



Hamamatsu MPPC

APD-like, operated in Geiger mode;
subdivided into many cells connected via
limiting (quenching) resistors

- Gain: 10^5 - 10^7 → Single-photon sensitivity
- Quick recovery time
- Fast
- Output \propto number of fired cells (up to 40,000/mm²)
- PDE: QE x geometrical factor 40-60% (peak)
- **BUT: high dark current, cross talk, non-linearity...high cost!**



G-APD: Where do we stand?

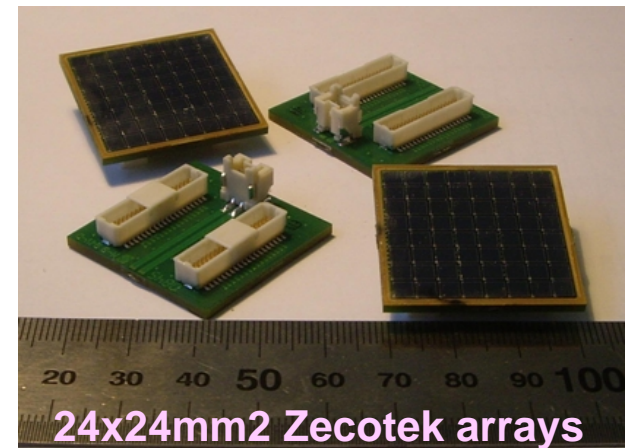
REVIEW: Renker & Lorenz
2009 *JINST* 4 P04004

Significant progress over the last 2-3 years:

- High **PDE** of **30-40%** for blue-green light (CPTA/Photonique, Hamamatsu, Zecotek)
- Reduction of **dark count** at room temperature to 300 kHz/mm² (Hamamatsu, Zecotek)
- **Low cross-talk** <1-3% (CPTA/Photonique, MEPhI, STMicroelectronics)
- Low temperature coefficient of ~0.3%/C (CPTA/Photonique)
- Fast timing ~**50 ps (RMS)** for **single photons** (all)
- **Large dynamic range** with 15 000 – 40 000 pixels/mm² (Zecotek)
- “Large area” of **3x3 mm²** (CPTA/Photonique, Hamamatsu, FBK, SensL, Zecotek, STMicroelectronics...) → reasonable arrays!
- **High cost/area**

Future

- **PDE >50-60%** @ 350-650 nm
- dark count rate <**100 kHz/mm²** at room temperature
- optical crosstalk <1%
- **active area >100mm²**
- high **DUV sensitivity** (PDE @ 128 nm ~20-40%)
- G-APD **arrays**: 6x6, 8x8 ...
- very fast position sensitive devices (**MAPS operated in Geiger mode**)
- radiation hard G-APDs -up to 10¹⁴ ÷ 10¹⁵ n/cm² (new materials: **diamond?**, **GaAs?**, **SiC?**, **GaN ...**)
- **Digital sensors...**
- Goal for cost ~**1 \$/mm²**



Applications:

Calorimetry, RICH, telescopes, PET, SciFi, **Noble Liquids**

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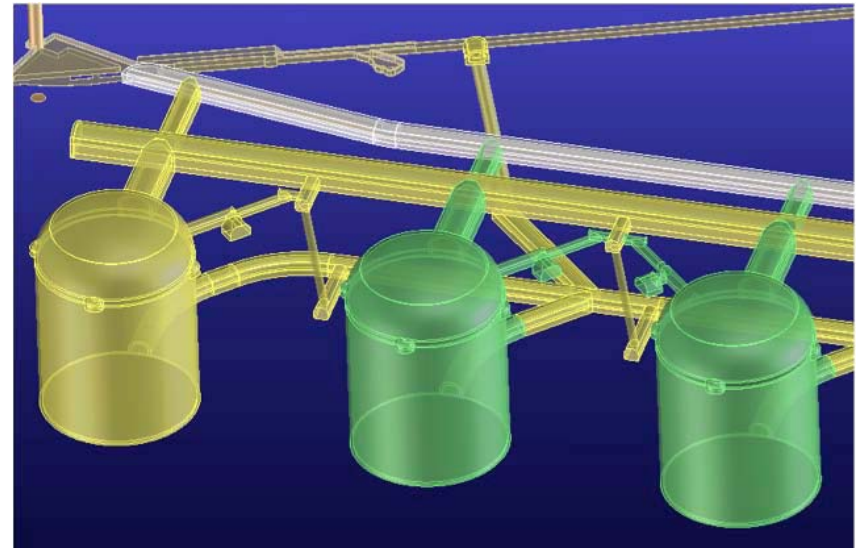
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12,000 m² of photon detectors per Each vessel

NATURE (via Mr. Liouville):

Irreducibly Large Illuminated Area

In Astroparticle Experiments



Strong internal signal concentration

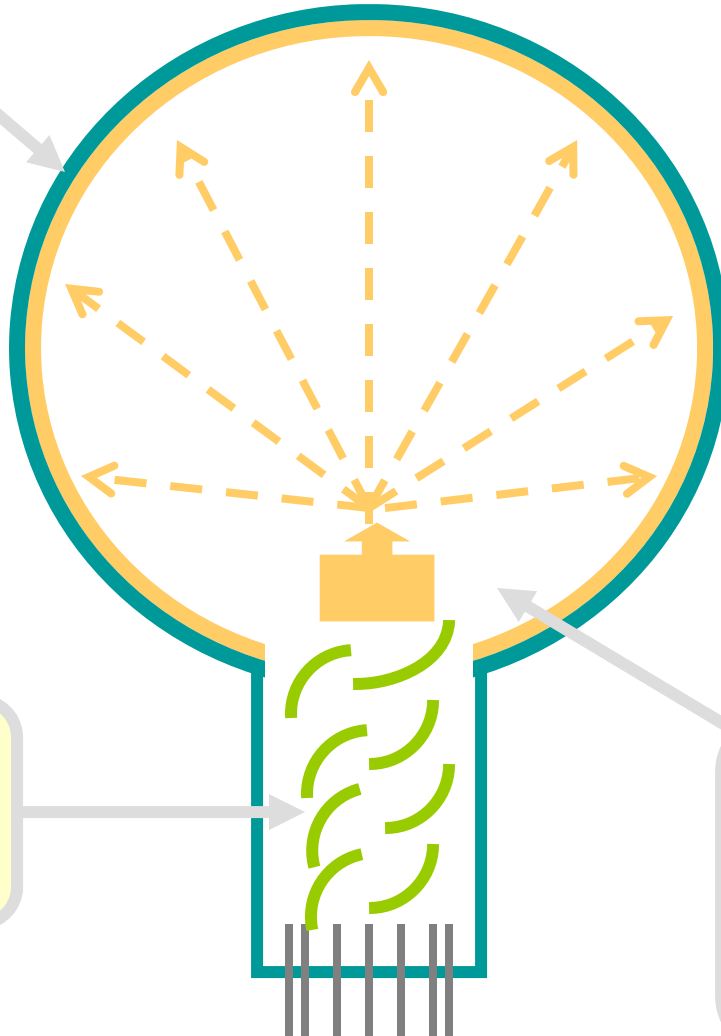
Vacuum + EM Forces

**(photon \rightarrow photo-electron \rightarrow ‘no
more Mr. Liouville*’)**

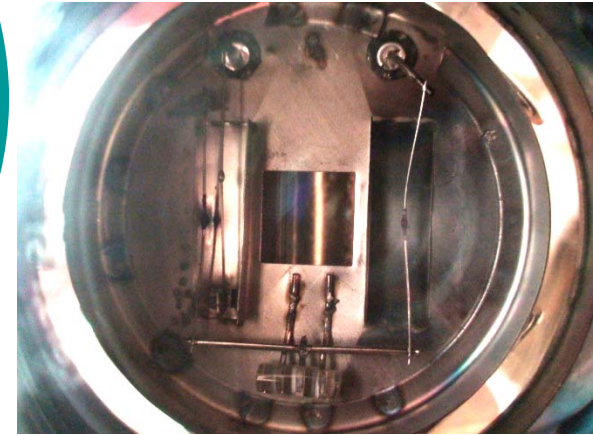
(*) for those photons

PMTs – 1960's Technology

~handmade



~handmade



**Cs, K, Na, Sb
Sources remain
inside!**

Development of Other Vacuum Devices



~1960



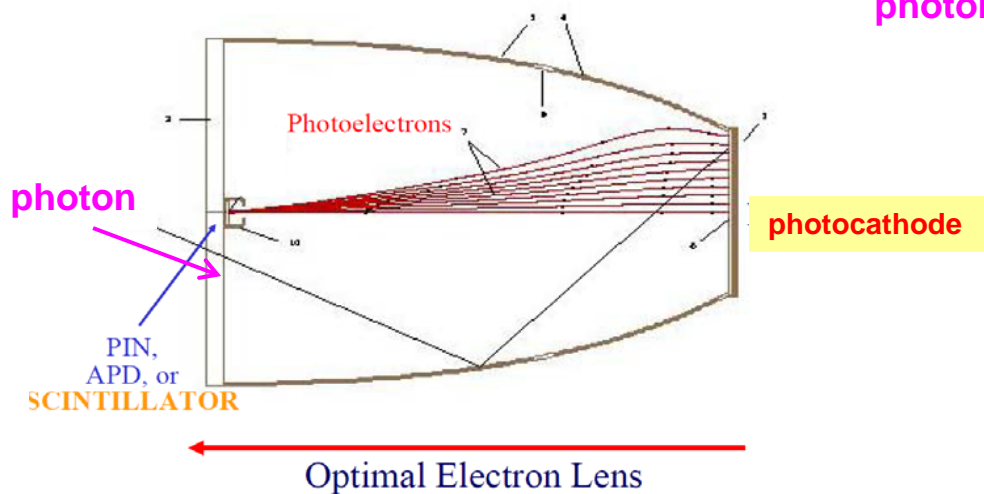
~2000

Production Cost '07 < \$500/m²

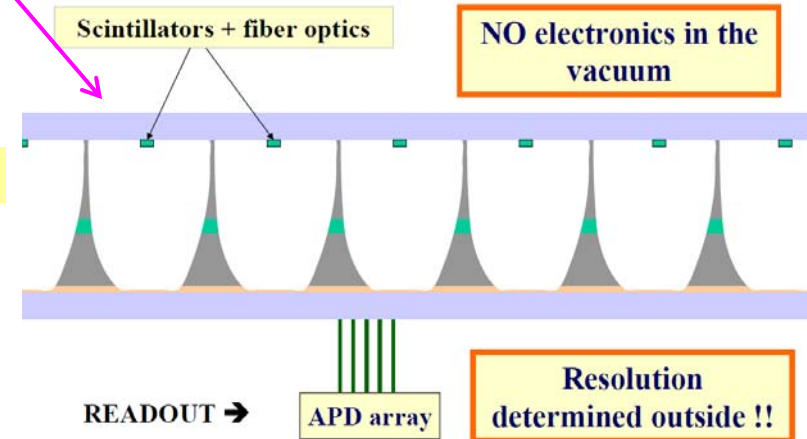
LARGE-AREA VACUUM PHOTON DETECTORS?

Ferenc LIGHT06

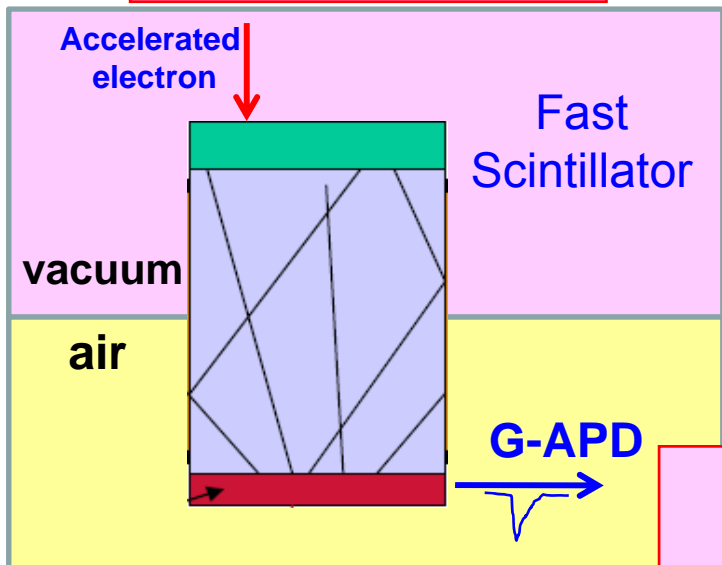
Ideal Light Concentrator
(takes the maximum of Liouville!)



Light Amplifier Concept

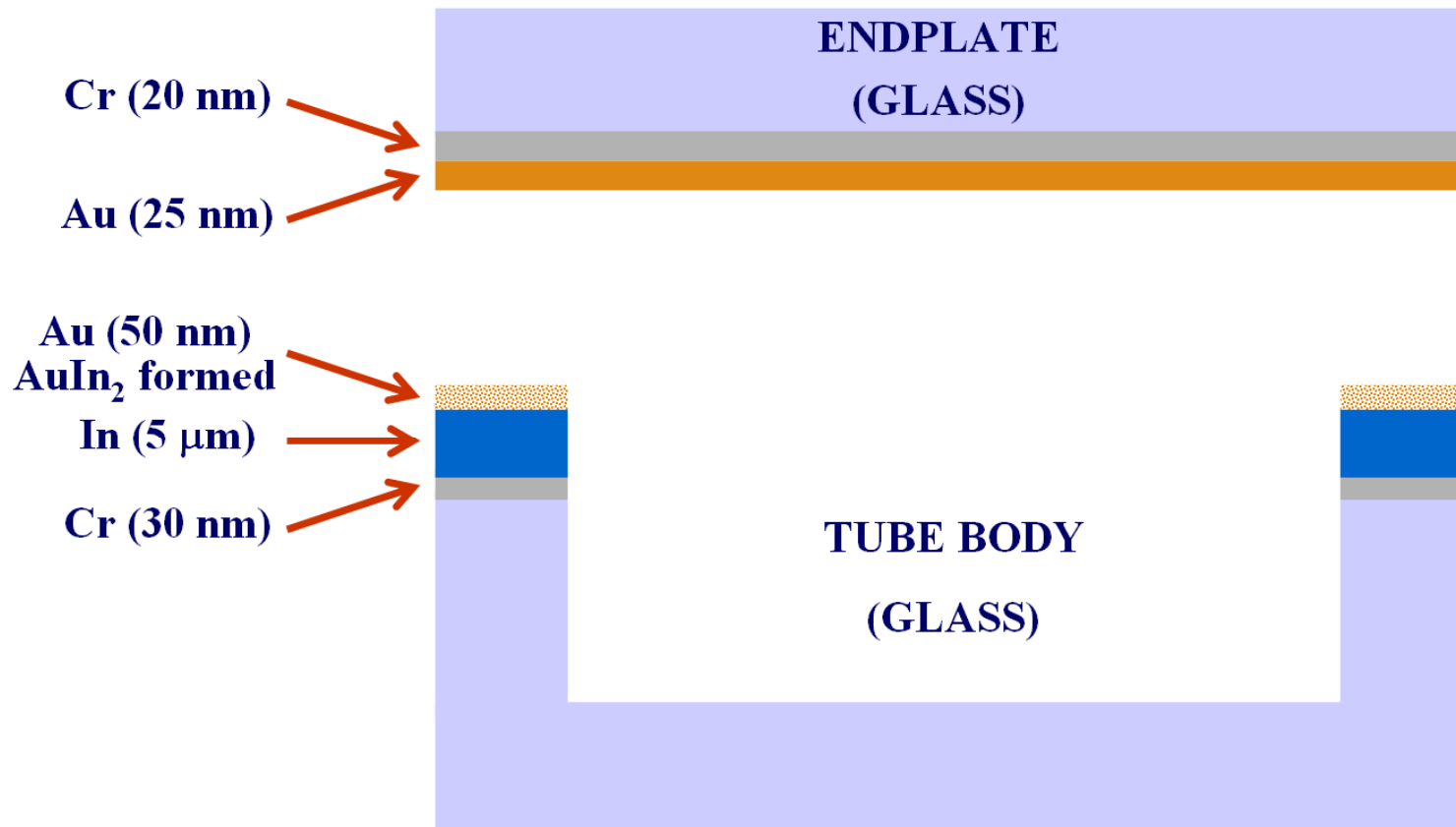


"LIGHT AMPLIFIER"



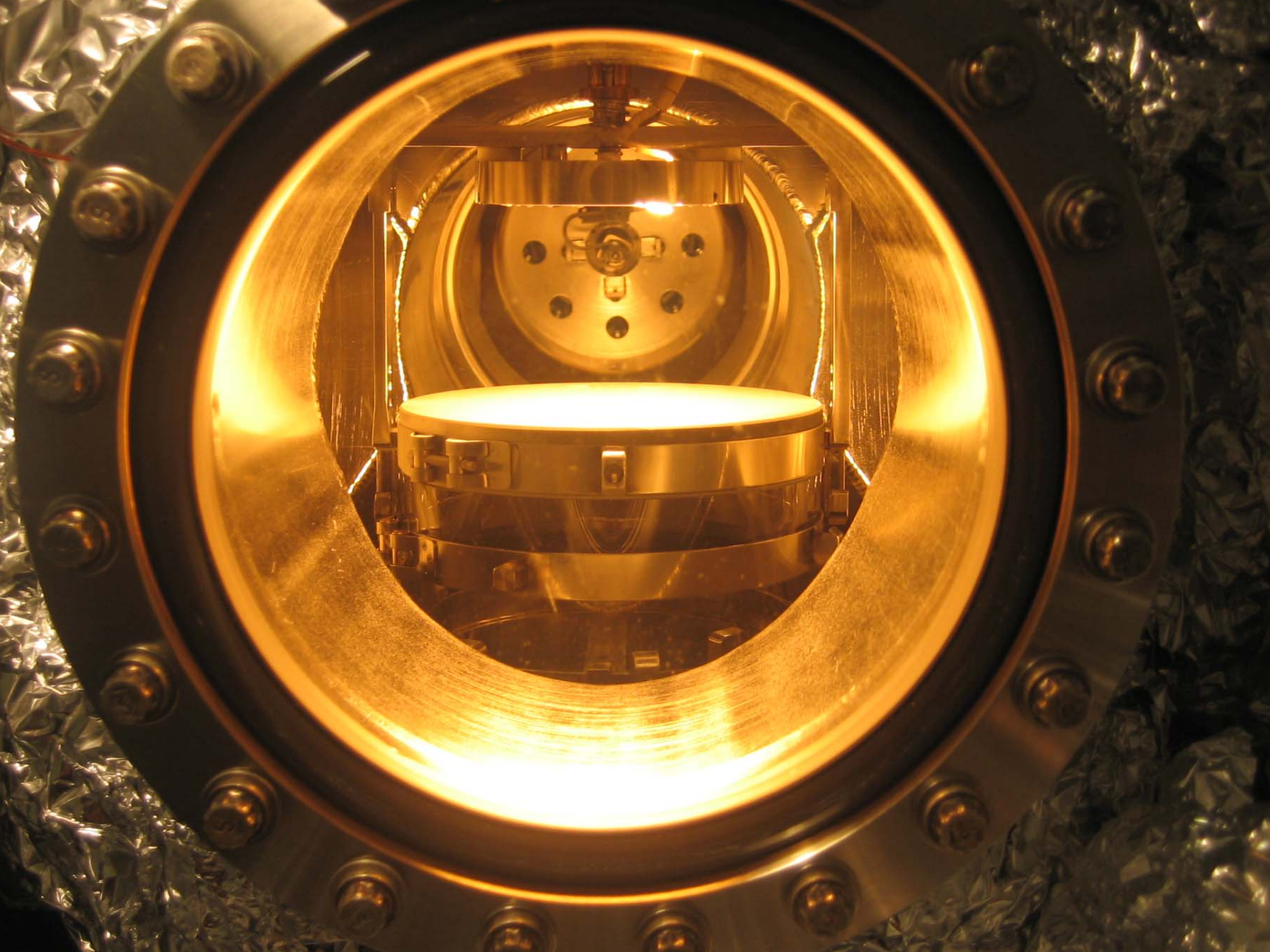
← Ferenc / Lorenz
NIMA 567(2006)166

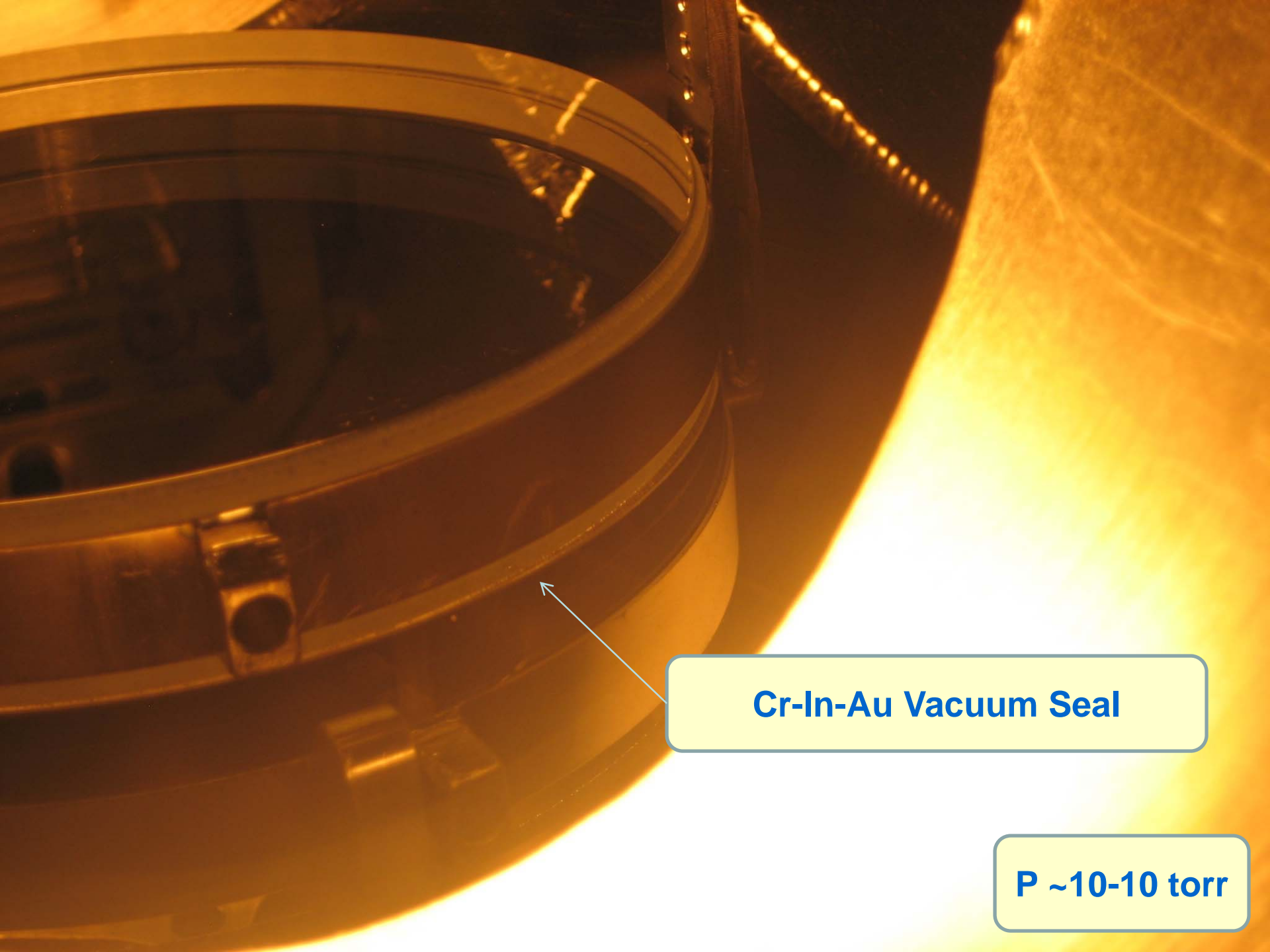
New Oxide-Free Thin-Film Indium Sealing Method



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.)



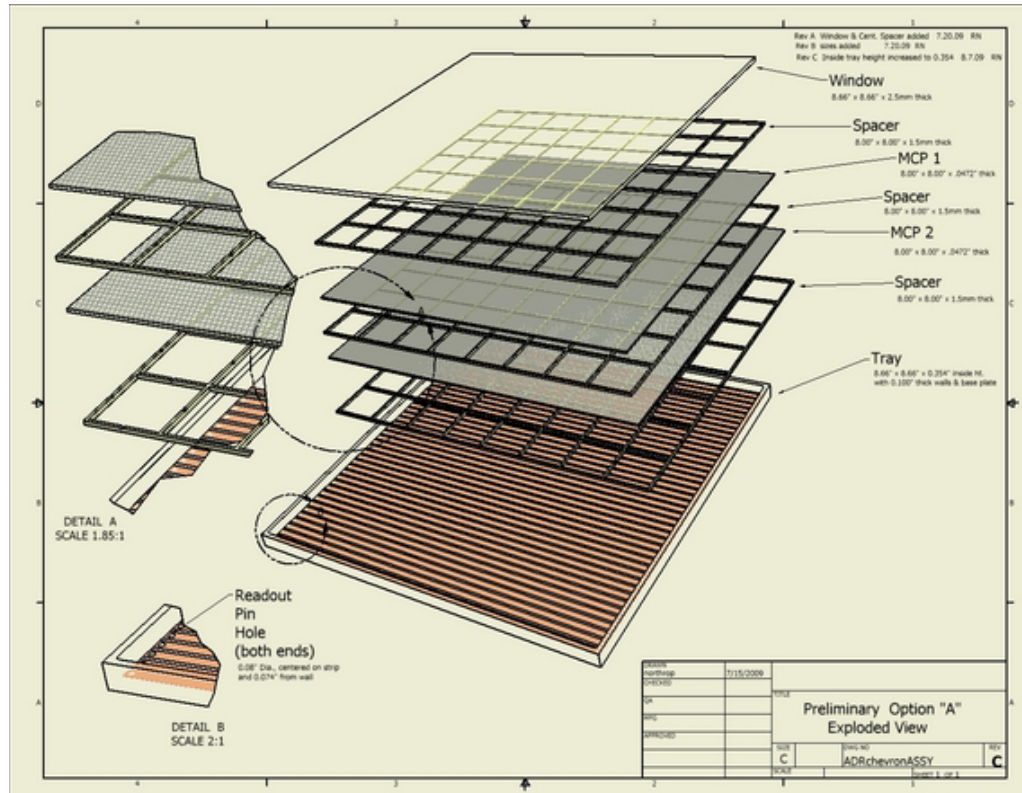


Cr-In-Au Vacuum Seal

P ~10⁻¹⁰ torr

Large Area, flat, vacuum MCP-Photon detectors

The Large Area Picosecond Photodetector (LAPPD) Collaboration



Search for economic methods for large-area MCPs

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

Lead by Henry Frisch, University of Chicago

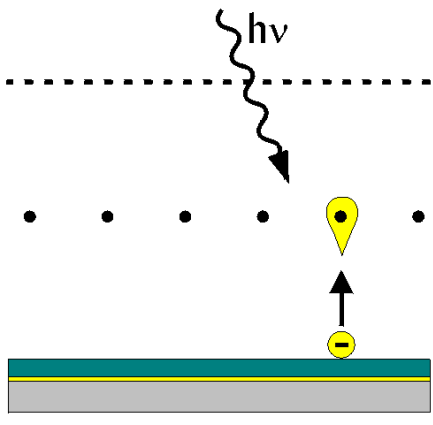
Large-area Flat Gas-Photomultipliers GPM

MWPC/CsI

mesh

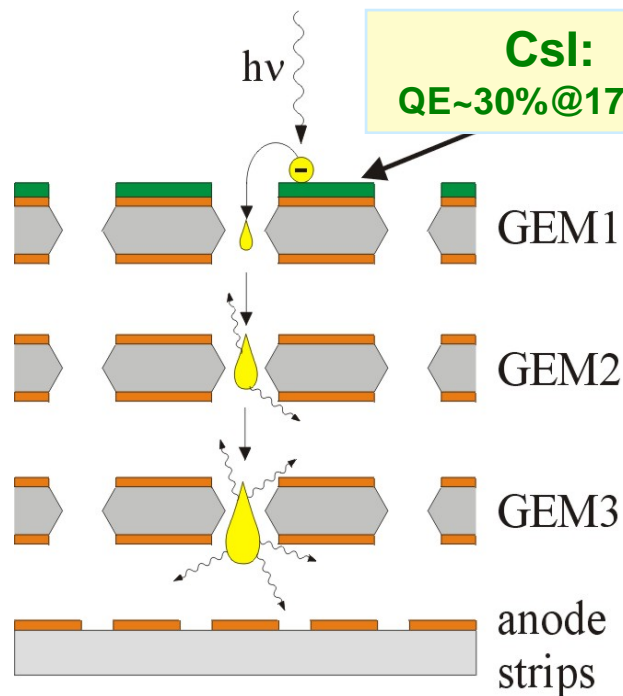
wires

photocathode
(CsI)



NEW: cascaded-GEM GPMs

A.B. et al, Weizmann



CsI:
QE~30%@170nm

LHC-Alice-RICH:
FIRST EVENTS Nov. 2009

Event 53 Total 3823
 + TRKxPC 10
 Δ Mip hits 0
 ○ Ckov hits 0
 ◊ Feed hits 0
 ● Digs 482
 * Clus 455

ddl = (0...13)
 RICH n → ddl 2n (left) & 2n+1 (right)
 phcat (0,2,4) left, phcat (1,3,5) right

1 MWPC/CsI module

ALICE-RICH

STARTED AT IRB
ZAGREB

UV: CsI photocathode
Gain: $>10^6$

Single-photon sensitivity
100 micron resolution
OK in high \vec{B}

Main application: RICH

CHALLENGE: visible-light Gas Photomultipliers!

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

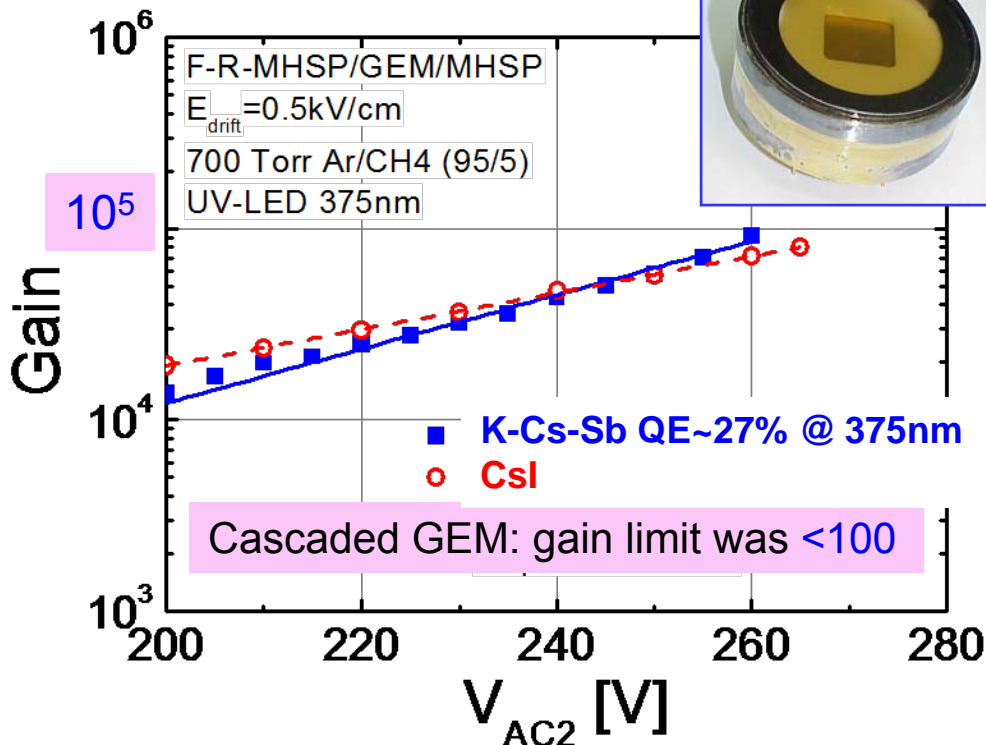
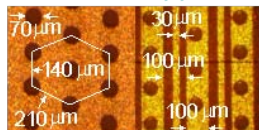
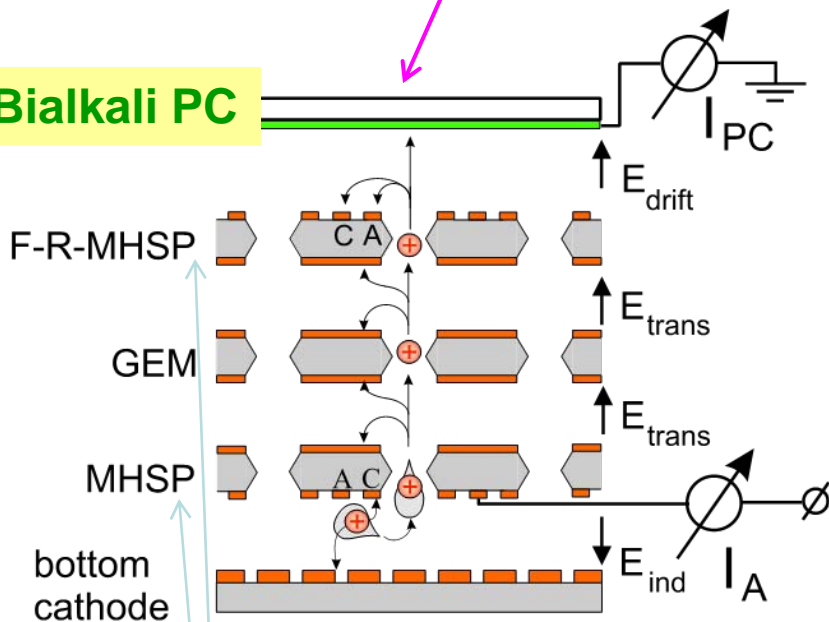
Sealed vis-GPM



Works uniquely due to efficient ion blocking

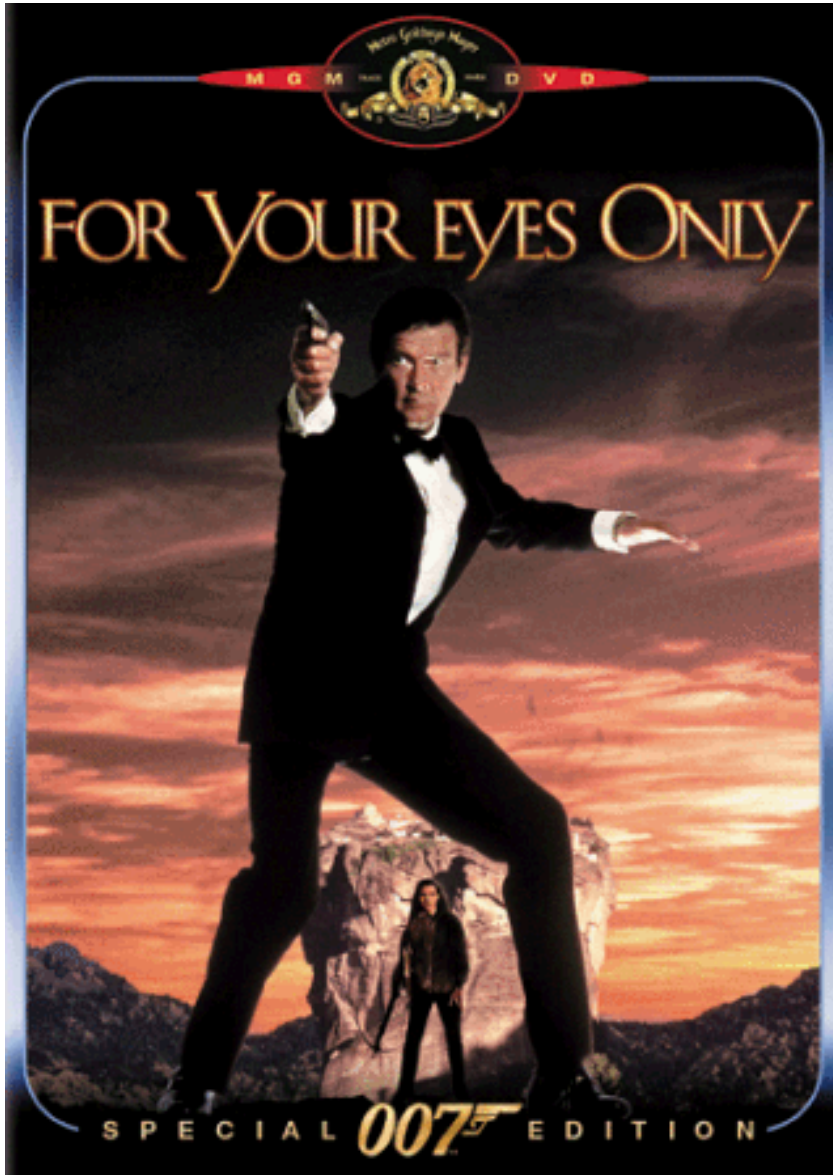
Visible photon

Bialkali PC



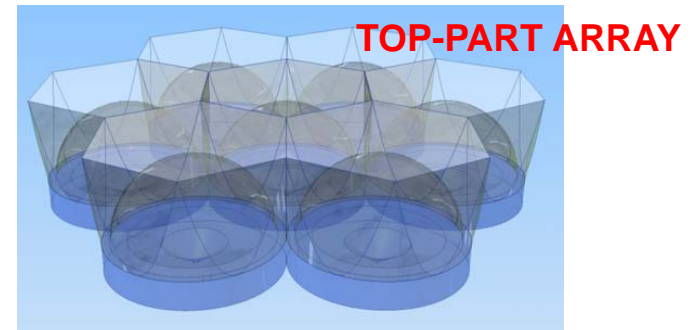
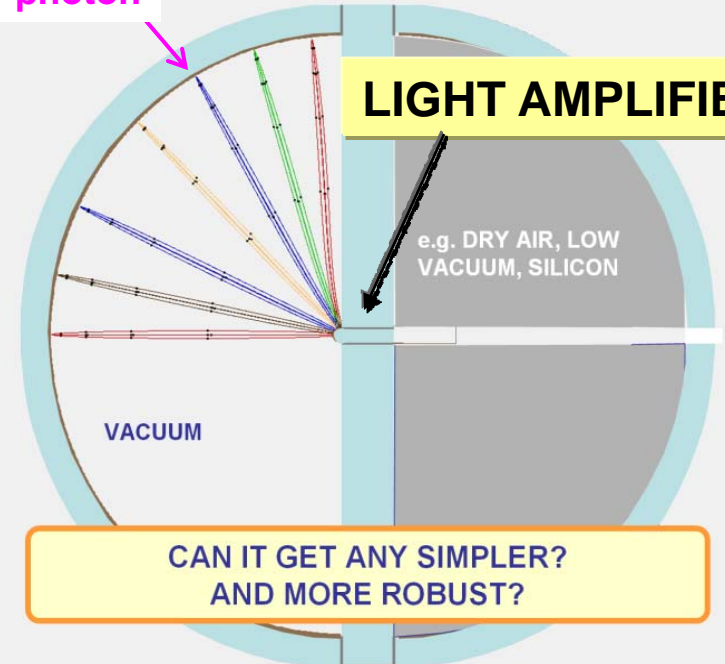
Gain $\sim 10^5$ + full photoelectron collection efficiency

- “flat-panel” large-area photon-imaging detectors insensitive to \vec{B}
- numerous applications: RICH, large Astro experiments...



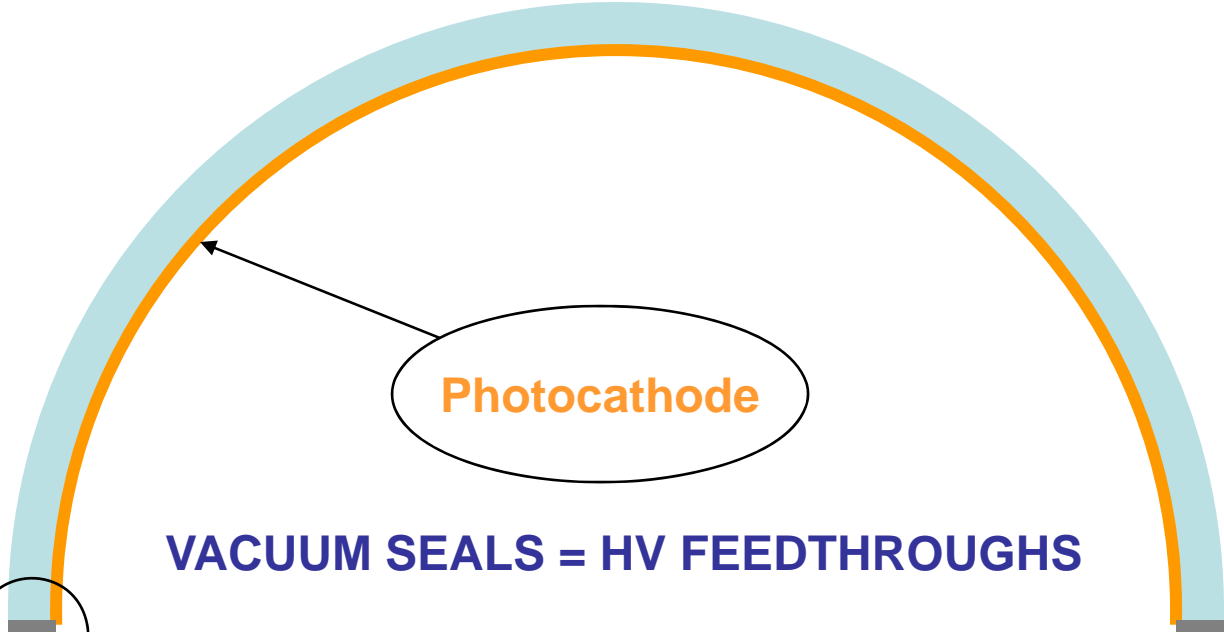
ABALONE

photon



Daniel Ferenc, Patent pending

ABALONE

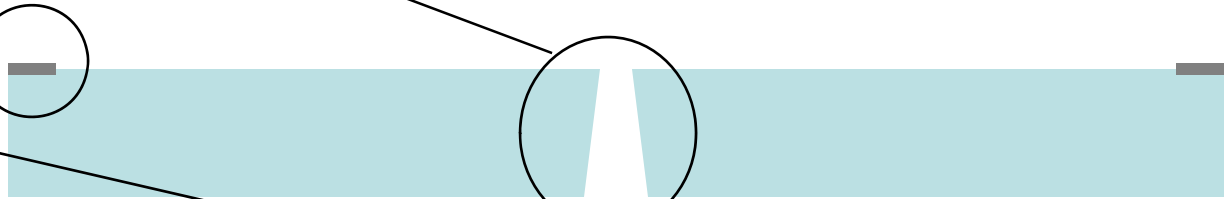


Cr
Au

VACUUM SEALS = HV FEEDTHROUGHS

Photocathode

In+Au
In
Au
Cr



ABALONE



MASS PRODUCTION - GLASS MOLDING



MASS PRODUCTION - GLASS MOLDING

IKEA®

Welcome to IKEA USA



My cart



My account



Join our email list!

All products

new

Living room

Bedroom

Kitchen



enlarge image

BLANDA

Serving bowl

size

5"

Price reflects the options selected above

\$2.99

Buy o

Sorry, th
website,
store.

Buy at

Prices or
2009 cat

Product information

Key features

Space-saving when stored; small sizes can be stacked inside larger sizes in the same series.

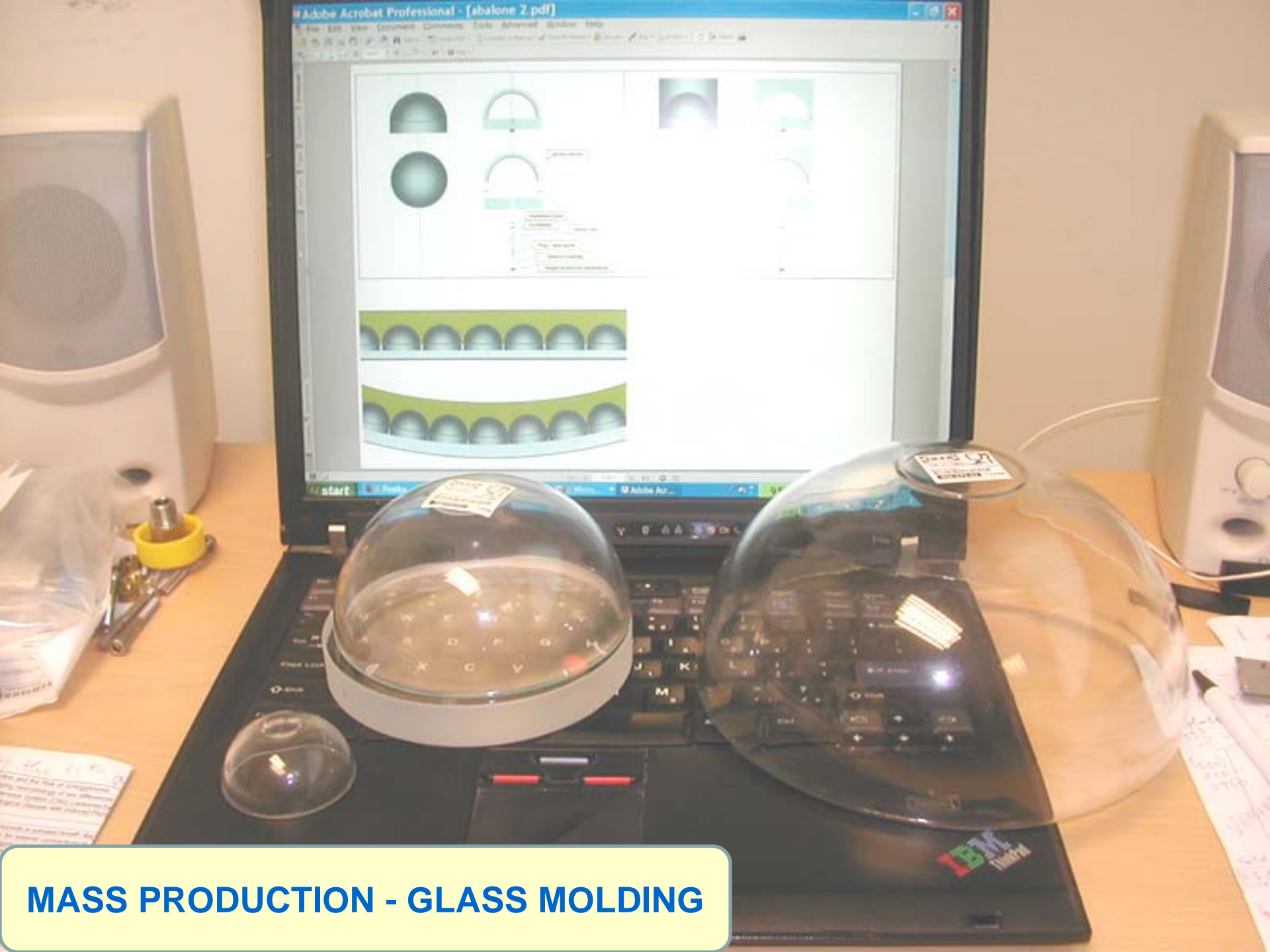
designer:

care instructions

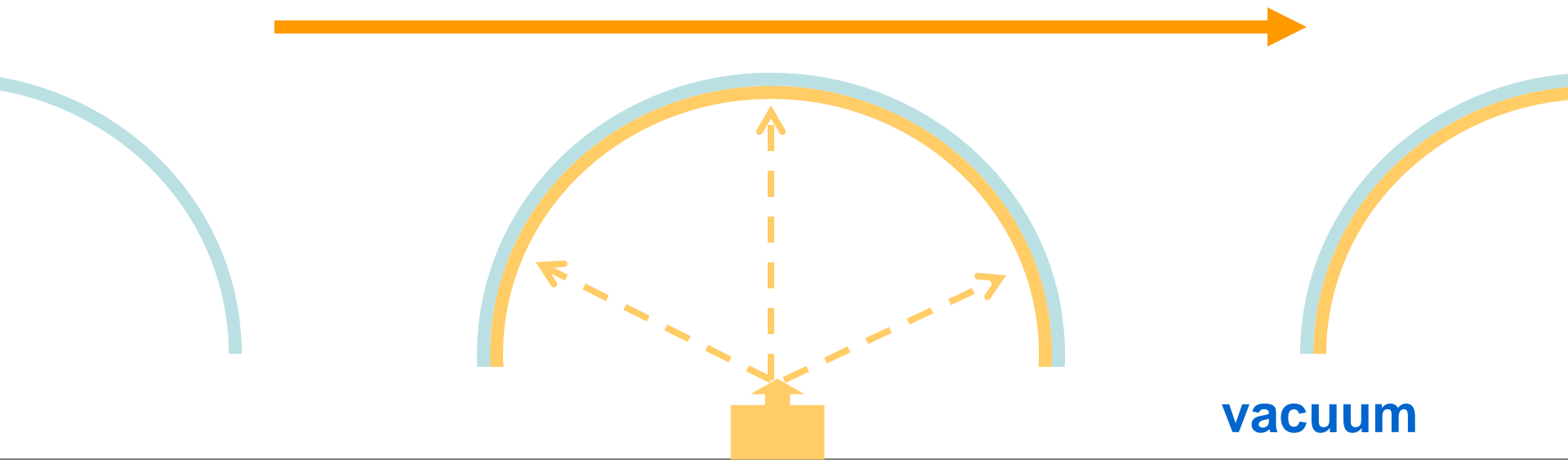
Dishwasher-safe.

product description & measurements

Glass



MASS PRODUCTION - GLASS MOLDING



MASS PRODUCTION – ABALONE ASSEMBLY

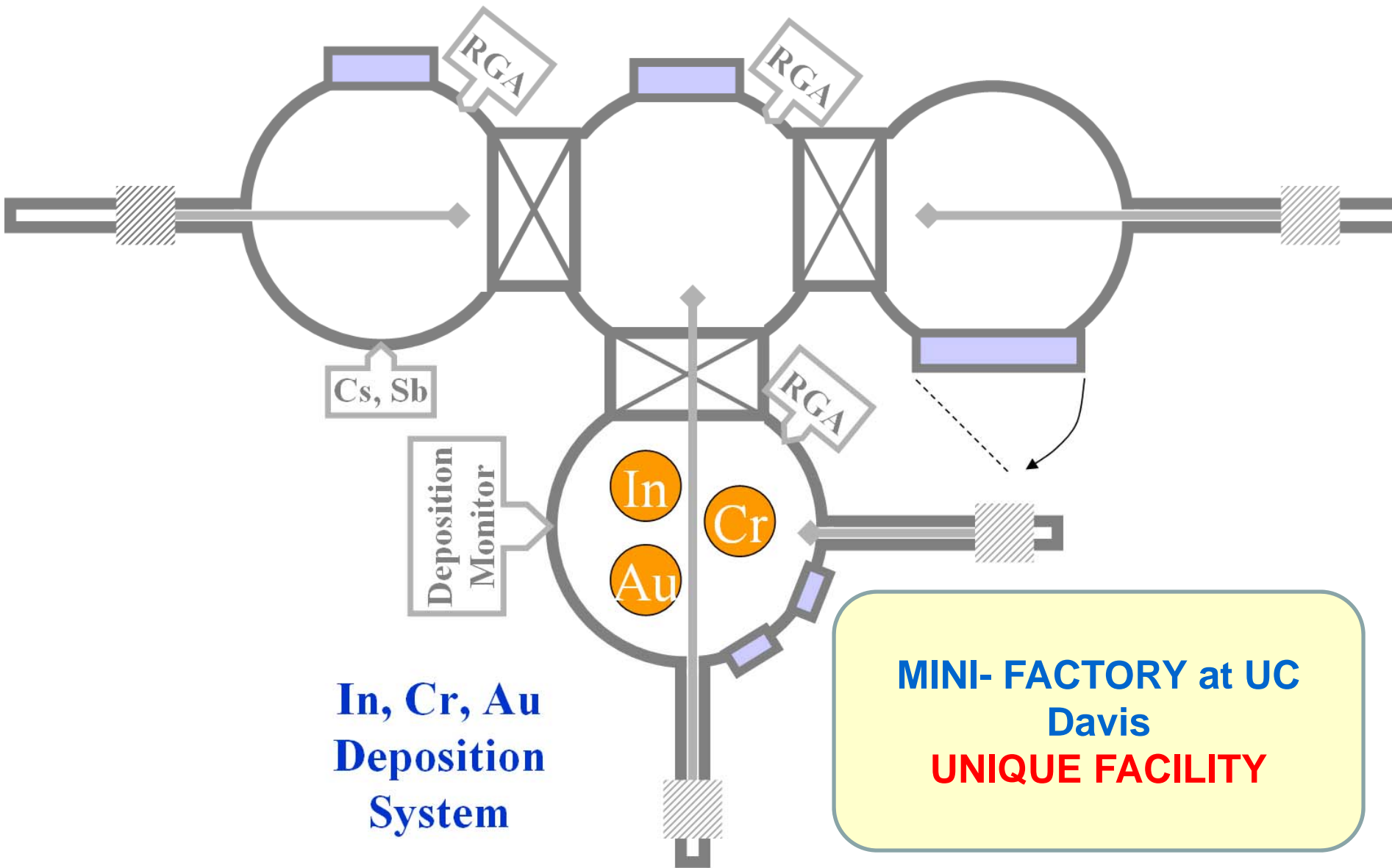
PRODUCTION LINE - VACUUM

THE KEY = OPEN ARCHITECTURE

**Photocathode
Deposition
Chamber**

**Sealing
Chamber**

**Load-Lock
Chamber**



Cs, Sb

RGA

RGA

RGA

Deposition
Monitor

In

Cr

Au

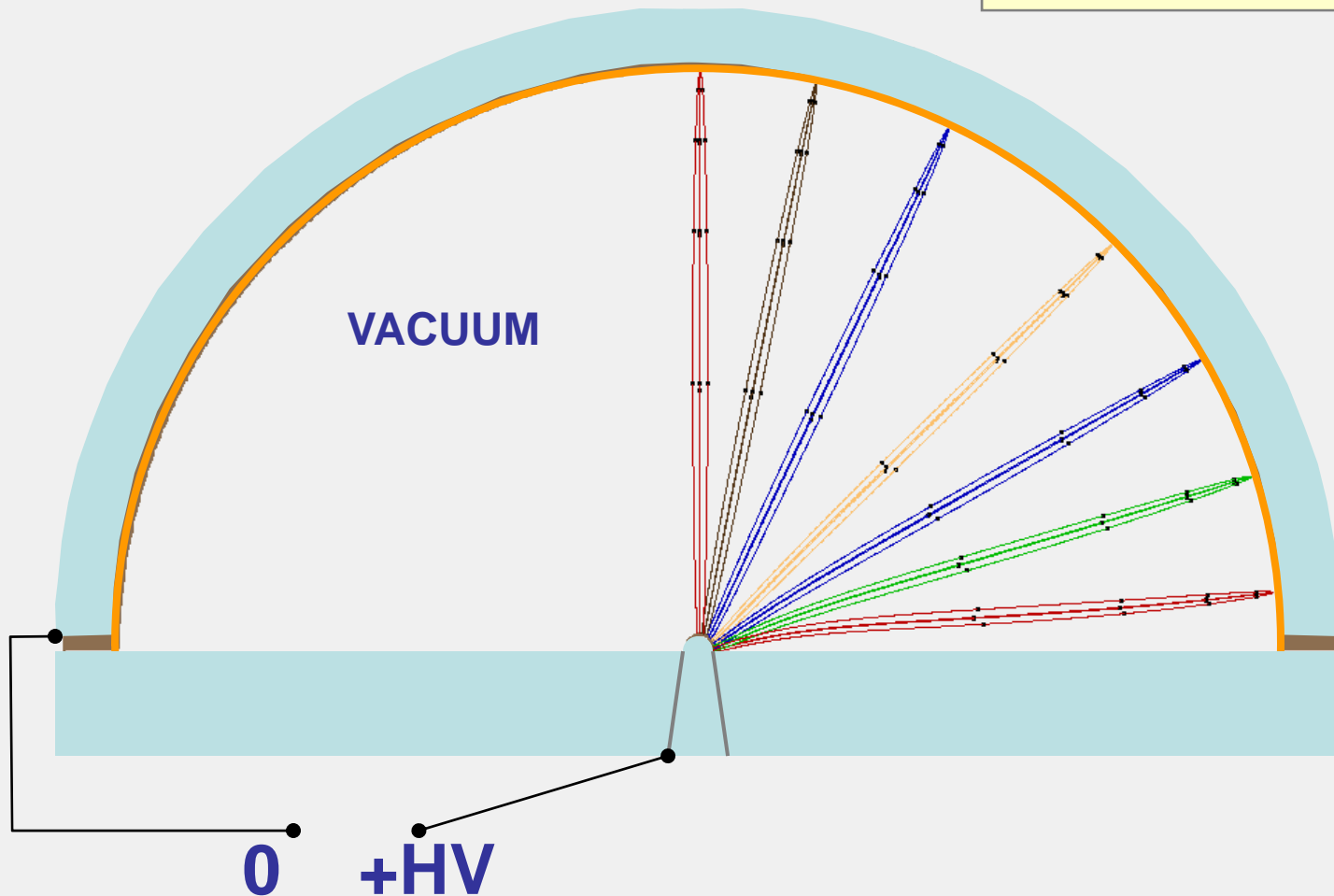
**In, Cr, Au
Deposition
System**

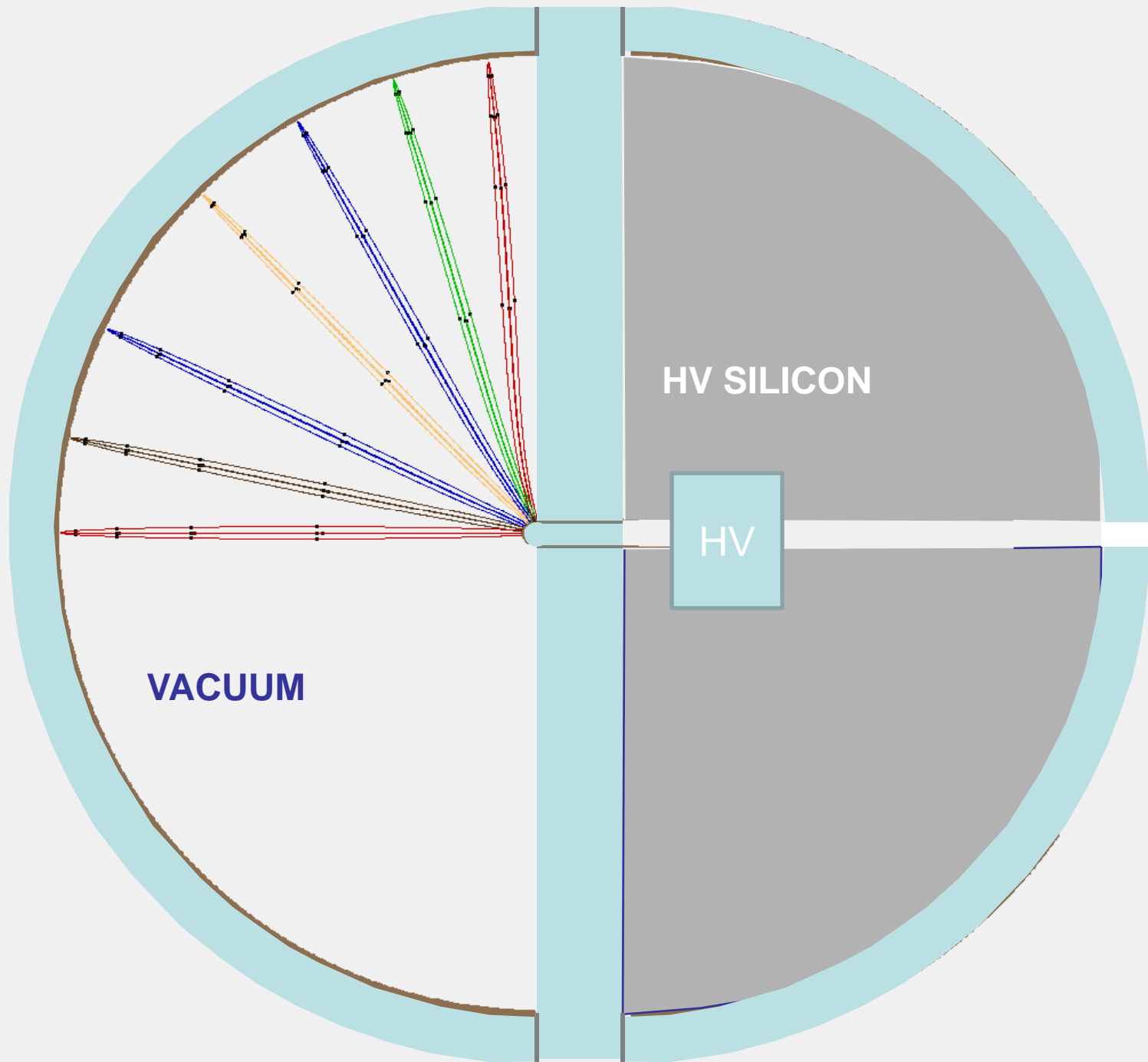
**MINI-FACTORY at UC
Davis
UNIQUE FACILITY**

ABALONE

Cr-In-Au Vacuum Seals
=
Voltage Feedthroughs

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

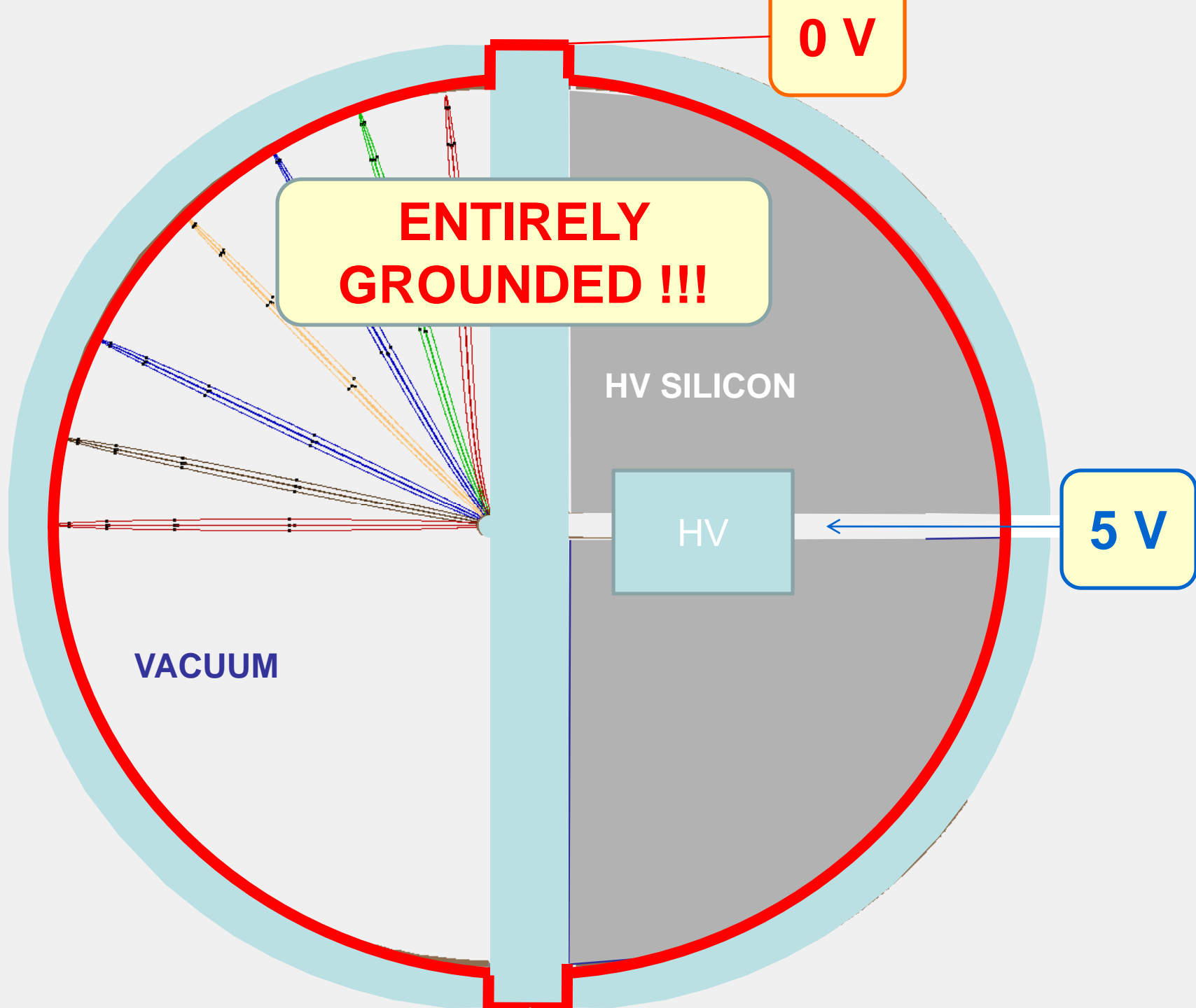




HV SILICON

HV

VACUUM



0 V

ENTIRELY
GROUNDED !!!

HV SILICON

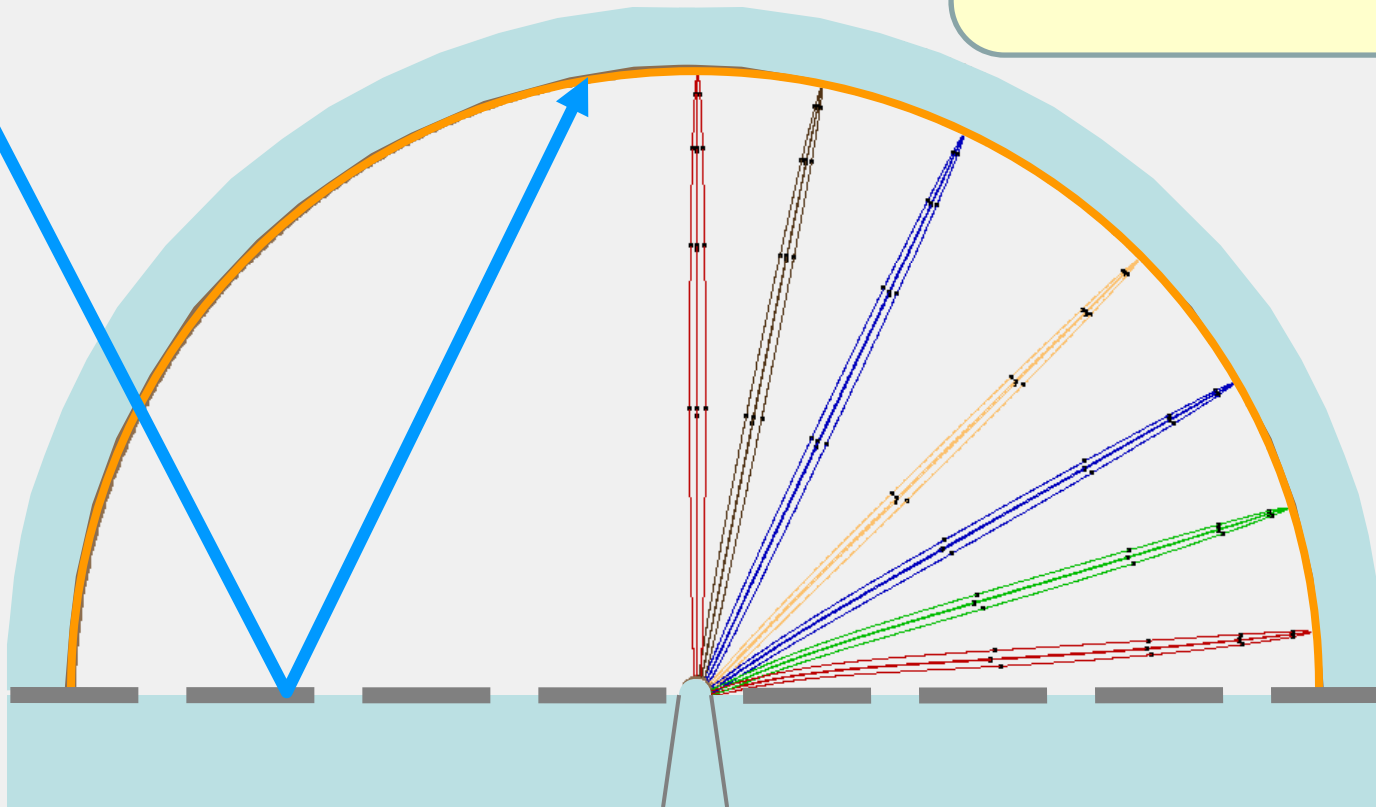
HV

5 V

VACUUM

**Floating Potential Rings
=
Reflectors & NEG Pumps**

**MAY BE MADE OF
~100% QUARTZ
(Low Radioactivity)**



Each photon \rightarrow 2 chances for detection

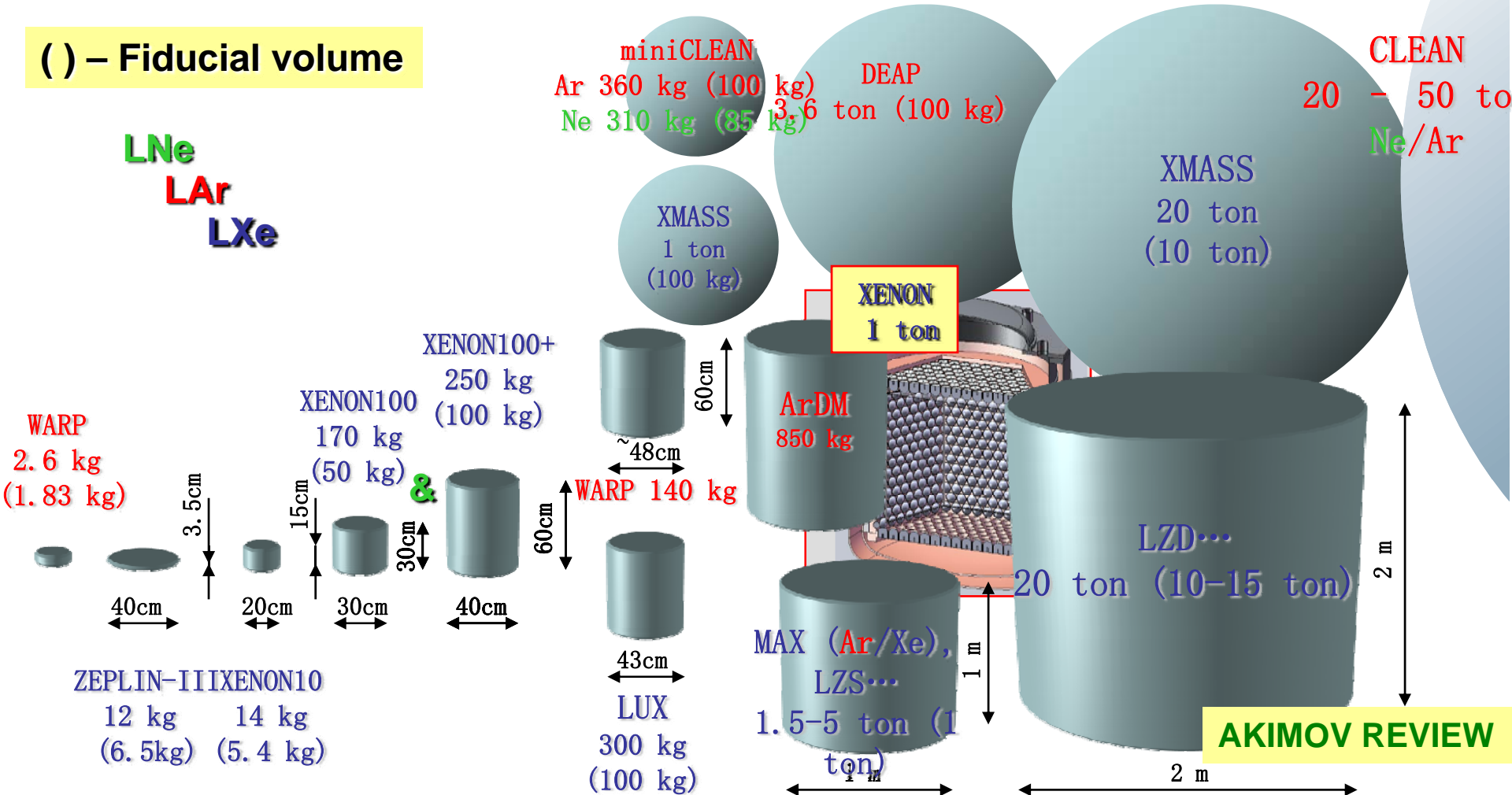
MANY NOBLE-LIQ DARK MATTER DETECTORS NEED RADIO-CLEAN PMT!

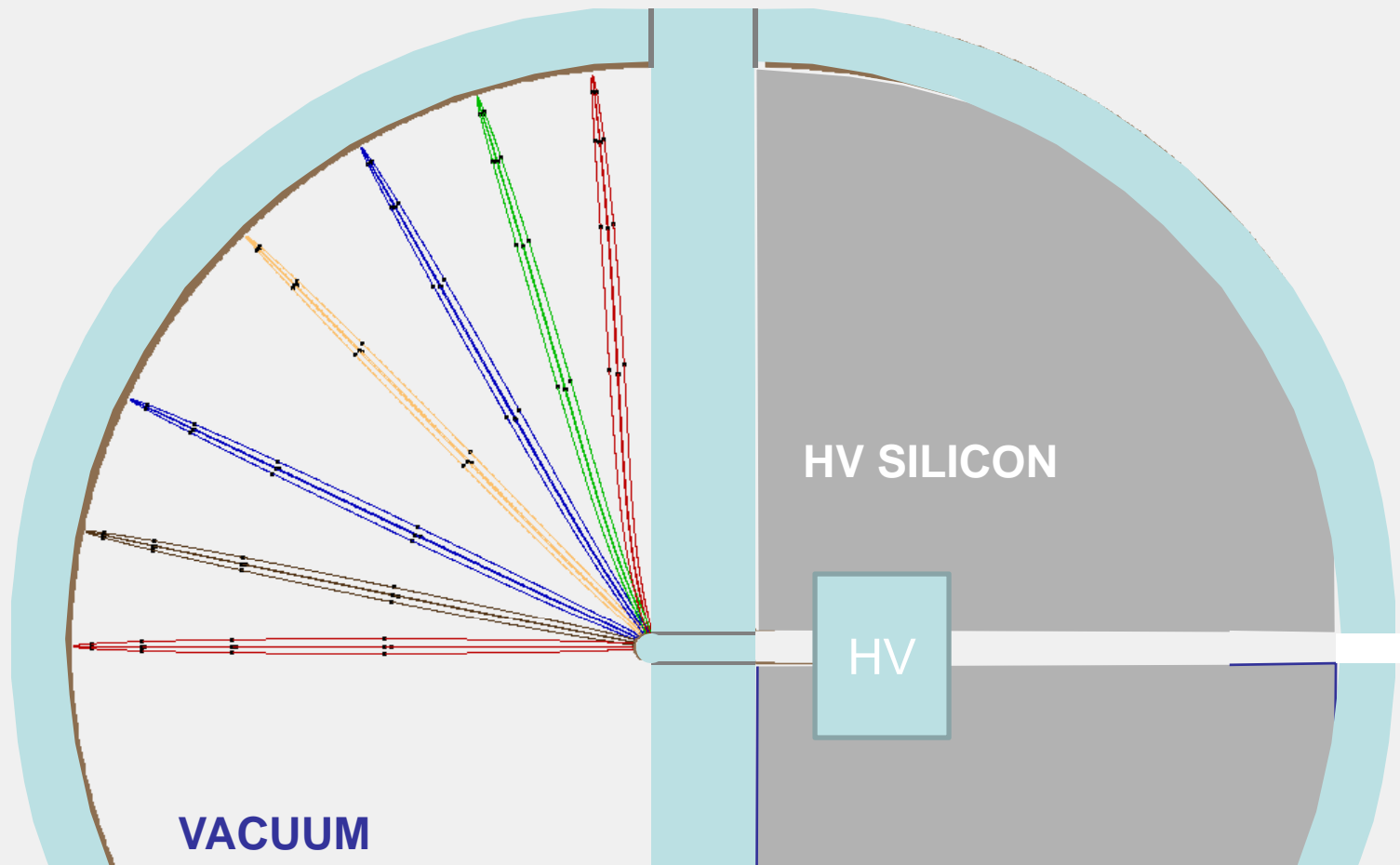
Completed, ongoing, deployment

Future ton- and multiton-scale

() – Fiducial volume

LNe
LAr
LXe

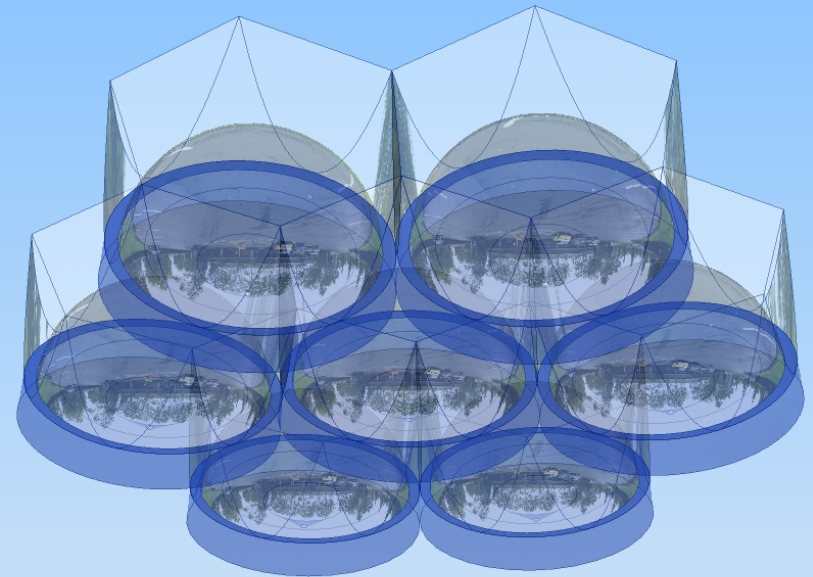
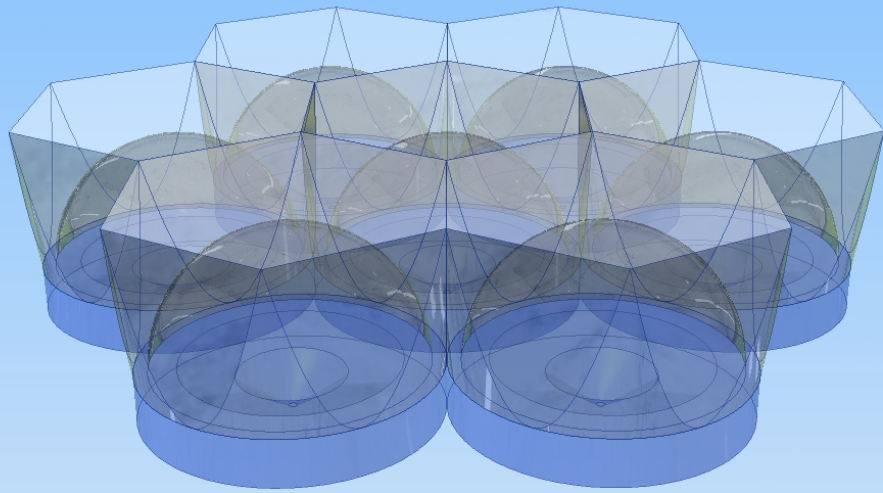




**CAN IT GET ANY SIMPLER?
AND MORE ROBUST?**

BACK TO A FLAT PANEL PHOTODIODE WITH ZERO DEAD AREA

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



ABALONE PRODUCTION LINE

GLASS
INDUSTRY

Experiments, nuke-
monitors, medical

STARTUP COMPANY

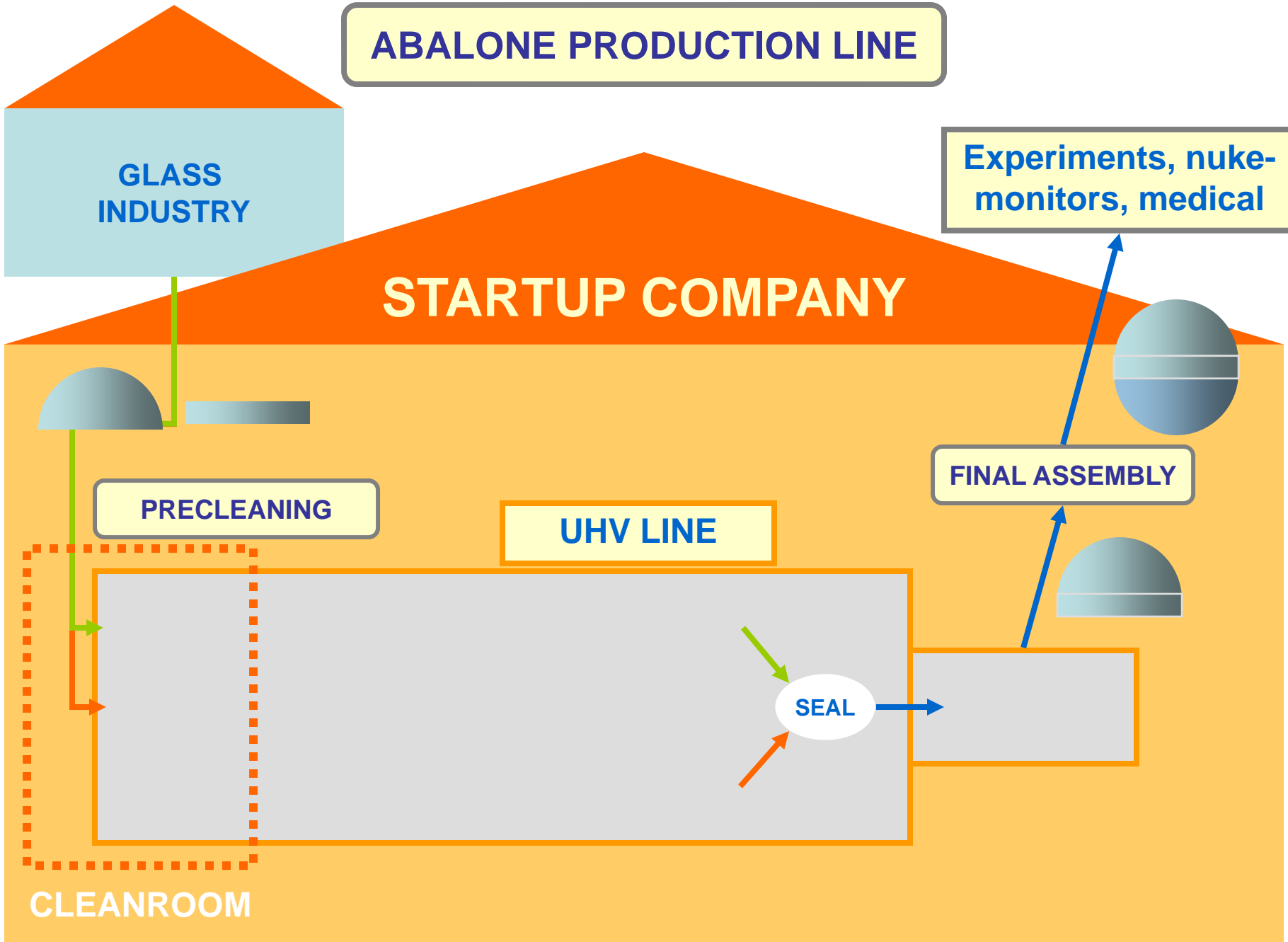
PRECLEANING

UHV LINE

FINAL ASSEMBLY

SEAL

CLEANROOM



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→ NUCLEAR NONPROLIFERATION**

R&D STATUS

- **In/Cr/Au Thin-Film Vacuum Sealing – FINISHED**
- **Light Amplifier Scintillator – SOME NEW (ultrafast+efficient) MATERIALS AVAILABLE, TO BE TESTED**
- **G-APD Readout – OPTIMIZATION UNDER WAY in Split**
- **Glass Molding – KNOWN TO WORK, NEEDS ACTION**
- **Quartz Machining – OUR R&D (with Behm Quartz) IS FINISHED, PURCHASE REQUESTED**
- **OVERALL PRODUCTION LINE OPTIMIZATION – NEEDS MORE FUNDING**
- **STARTUP FORMATION – AN ATTEMPT UNDER WAY**

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.**