ABALONE MASS-PRODUCTION PHOTOSENSOR TECHNOLOGY:

ULTRALOW PRODUCTION AND INTEGRATION COSTS, EXCEPTIONAL PERFORMANCE AND ROBUSTNESS, LOW RADIOACTIVITY and MORE

Daniel Ferenc,
Andrew Chang, David Johnson, Chris Ducote
Physics Department, UC Davis

Important contributions by late
Eckart Lorenz, MPI Munich and UC Davis
Tom Ypsilantis, CERN and EP Paris

Colloquium at the Lawrence Berkeley Laboratory, June 24. 2015

ABALONE Home Page | Contact Ferenc Lab | Contact UC Davis Technology Transfer

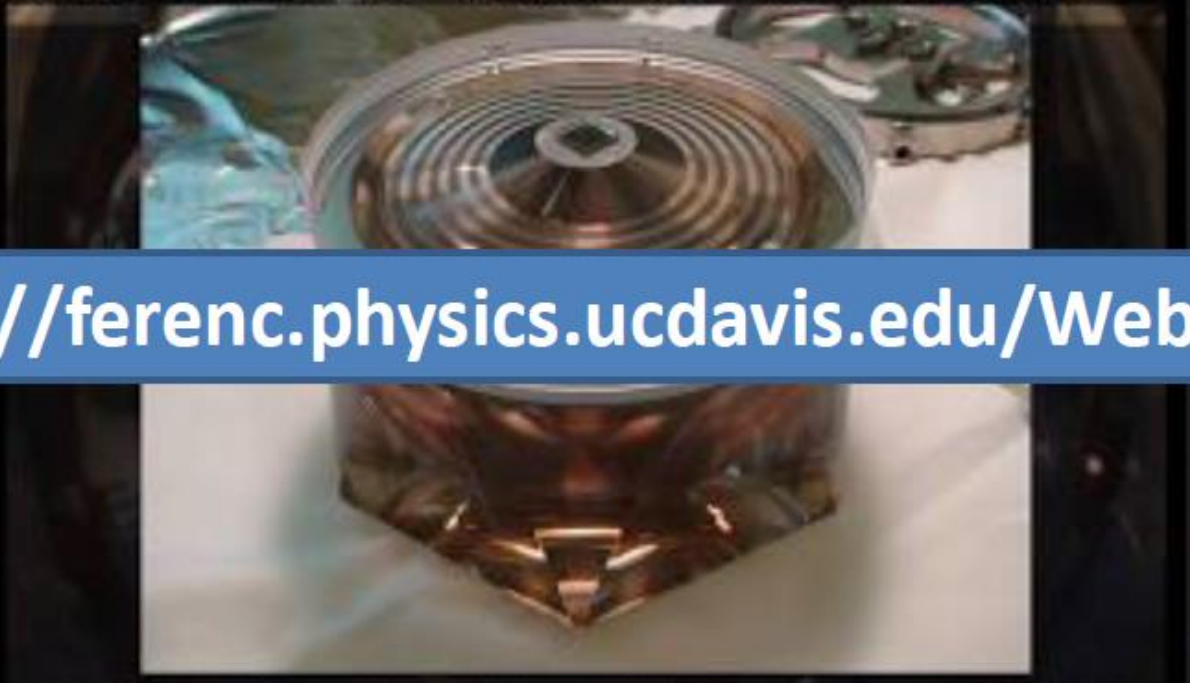
ABALONE

NOVEL MASS-PRODUCTION PHOTOSENSOR TECHNOLOGY

ABOUT • ABALONE • PHYSICS • PET SCANNER • HISTORY • CREDIT • PUBLICATIONS • CONTACT • F.A.Q.

TECHNOLOGY

ABALONE APPLICATIONS – DARK-MATTER, ν DOUBLE-BETA DECAY...



NEUTRINO

http://ferenc.physics.ucdavis.edu/WebSite1

ABALONE PET
SCREENING FOR EARLY DETECTION OF CANCER

LOW-RADIATION PHYSICS
DARK MATTER; 2νBETA...

~100% ULTRAPURE FUSED SILICA + THIN FILMS OF SELCTED MATERIALS + SPECIAL-G-APD

→ UNBEATABLY LOW LEVEL OF RADIOACTIVITY ←

SUPPORTED BY:
→ 3 Advanced Detector Research Rewards (ADR), DOE
→ NNSA/DOE Grant
→ Proof Of Concept (POC) Award, University of California
→ Some UC Davis grants, private donations, etc.

→ ABALONE Photosensor technology → PATENT ISSUED YESTERDAY
VACUUM PHOTOSENSOR DEVICE WITH ELECTRON LENSING.
The U.S. Patent awarded on June 23, 2015, Patent No. 9,064,678.

→ New patent submitted recently, PCT/US15/031188, more patents coming.

→ 2 older patents are also relevant.

➔ STARTUP COMPANY HAS BEEN FORMED: 'PHOTONLAB, Inc.'

Some previous presentations:
→ D.F., "ABALONE TECHNOLOGY AND PROTOTYPE TEST RESULTS," LIGHT'14, October 2014, Ringberg.
→ Daniel Ferenc, "PHOTON COUNTING IN THE NEXT DECADE,"
KEYNOTE LECTURE at the ASPERA TECHNOLGOY FORUM, Munich, Oct. 2010,
→ Daniel Ferenc, "NEW PHOTOSENOR CONCEPTS AND PRODUCTION METHODS
-VACUUM AND GASEOUS PHOTOSENSORS ,"
SHORT COURSE, IEEE Nuclear Science Symposium, Knoxville TN, Nov. 2010.

OUTLINE

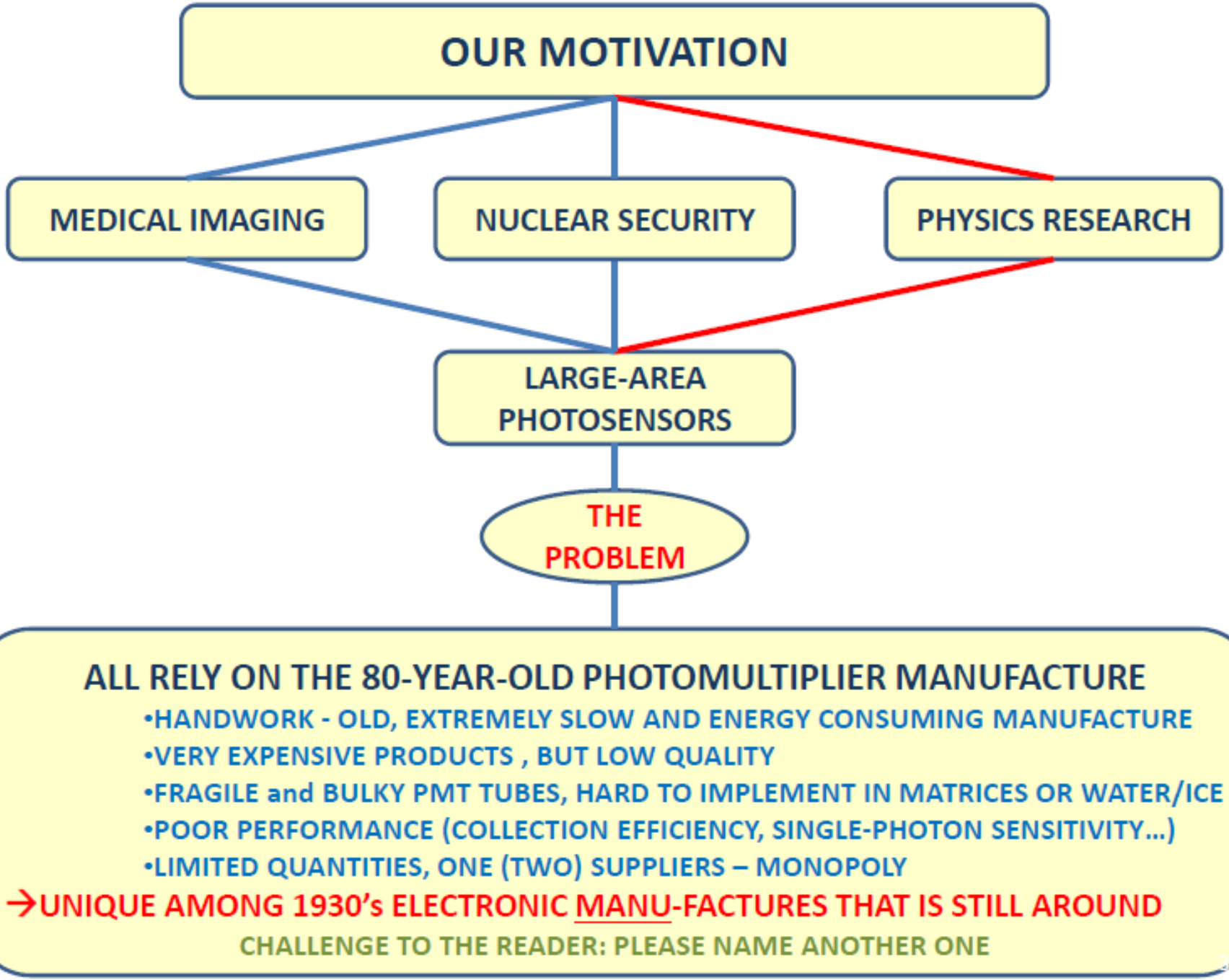
THE PROBLEM

THE ABALONE TECHNOLOGY AS THE SOLUTION

ABALONE PHOTOSENSOR PROTOTYPE PERFORMANCE
(25 MONTHS OF CONTINUOUS OPERATION)

SELFIES → TAKEN BY ABALONE PROTOTYPE:

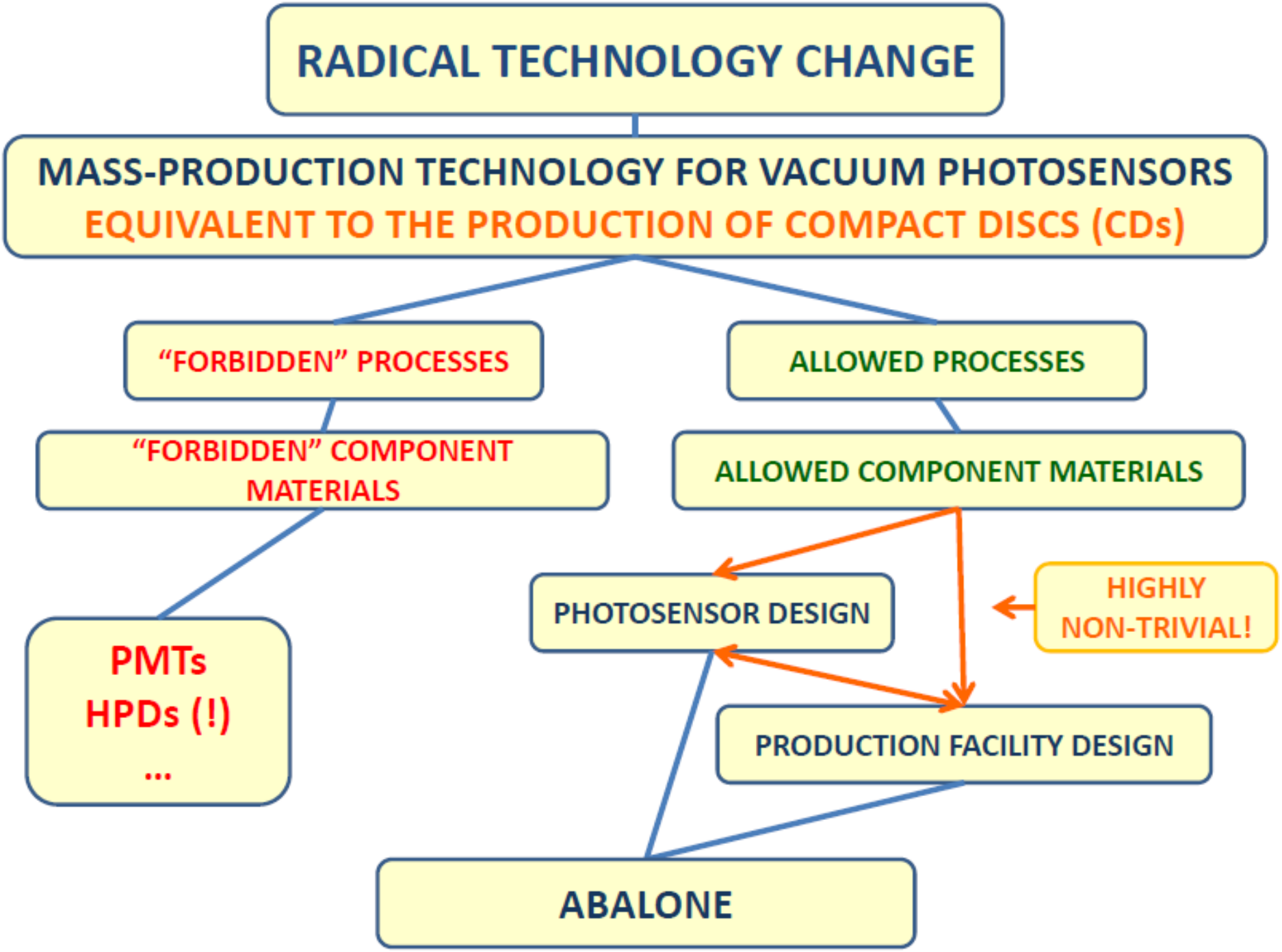
- → LOOK HOW CLEAN AND EMPTY I AM (> 10X LESS AFTERPULSING THAN THE BEST PhotoMultiplier Tubes)
- → LOOK HOW I CLEAN MYSELF INTERNALLY (by 3 complementary methods)
- → LOOK HOW I RESOLVE SINGLE PHOTONS
- → LOOK HOW SINGLE PHOTONS ARE DISTINGUISHED FROM THE PEDESTAL
- → LOOK HOW I FORM LARGE-AREA THIN-SHELL DETECTORS
- → IMAGINE HOW USEFUL MAY I BE FOR YOUR NEXT-GENERATION DREAM TOY


OUR MOTIVATION
MEDICAL IMAGING
NUCLEAR SECURITY
PHYSICS RESEARCH
LARGE-AREA PHOTOSENSORS
THE PROBLEM
ALL RELY ON THE 80-YEAR-OLD PHOTOMULTIPLIER MANUFACTURE
•HANDWORK - OLD, EXTREMELY SLOW AND ENERGY CONSUMING MANUFACTURE
•VERY EXPENSIVE PRODUCTS , BUT LOW QUALITY
•FRAGILE and BULKY PMT TUBES, HARD TO IMPLEMENT IN MATRICES OR WATER/ICE
•POOR PERFORMANCE (COLLECTION EFFICIENCY, SINGLE-PHOTON SENSITIVITY…)
•LIMITED QUANTITIES, ONE (TWO) SUPPLIERS – MONOPOLY
→UNIQUE AMONG 1930's ELECTRONIC MANU-FACTURES THAT IS STILL AROUND
CHALLENGE TO THE READER: PLEASE NAME ANOTHER ONE

WITH A FINE TOUCH OF A GENIUS

WITH A FINE TOUCH OF A GENIUS

OUR CHOICE !


RADICAL TECHNOLOGY CHANGE
MASS-PRODUCTION TECHNOLOGY FOR VACUUM PHOTOSENSORS
EQUIVALENT TO THE PRODUCTION OF COMPACT DISCS (CDs)
"FORBIDDEN" PROCESSES
ALLOWED PROCESSES
"FORBIDDEN" COMPONENT MATERIALS
ALLOWED COMPONENT MATERIALS
PMTs
HPDs (!)
...
PHOTOSENSOR DESIGN
HIGHLY NON-TRIVIAL!
PRODUCTION FACILITY DESIGN
ABALONE

ABALONE TECHNOLOGY—ALLOWED PROCESSES AND MATERIALS

MASS PRODUCTION

→ MODERN VACUUM PROCESSING
- →MASS-PRODUCED COMPONENTS, MADE OF CHEAP MATERIALS
- →FAST, CONTINUOUS PRODUCTION LINE: COMPONENTS IN → PRODUCT OUT
- →AUTOMATIC PROCESSING

(The term 'COMPONENT' defined on next slide)

"FORBIDDEN" PROCESSES
→ CLEANING BY BAKEOUT
→ BRAZING, SPOT-WELDING
→ HANDWORK

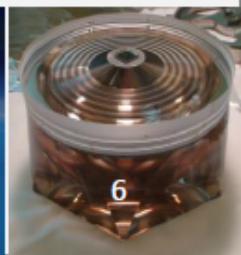
"FORBIDDEN" COMPONENT MATERIALS
→ METALS
→ GLASS-TO-METAL JOINTS
→ CERAMICS
→ CERAMIC BRAZES
→ DIODES, PHOTODIODES
→ MICROSCOPIC FEATURES

→ALL AVOIDABLE WITH ABALONE

ALLOWED PROCESSES
→ FAST REACTIVE PLASMA CLEANING
→ THIN FILM VACUUM DEPOSITION
→ ROBOTIC TRANSPORT AND ASSEMBLY

ALLOWED COMPONENT MATERIALS
→ GLASS
→ FUSED SILICA
→ DIELECTRIC CRYSTALS

→ ALREADY SUCCESSFULLY IMPLEMENTED



ABALONE TECHNOLOGY

MASS-PRODUCING PHOTOSENSORS LIKE CDs

COMPONENT 1

COMPONENT 2

COMPONENT 3

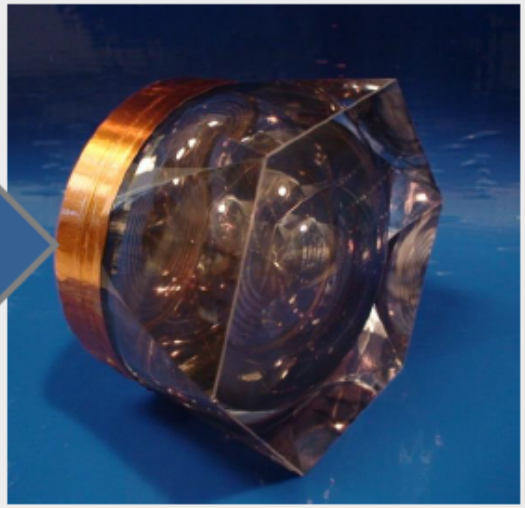
UH VACUUM PRODUCTION FACILITY (Ferenc Lab, UC Davis)

METALS ARE EXCLUSIVELY DEPOSITED AS THIN FILMS

- PHOTOCATHODE
- SEALING ALLOY
- GETTER

METALS

PRODUCT



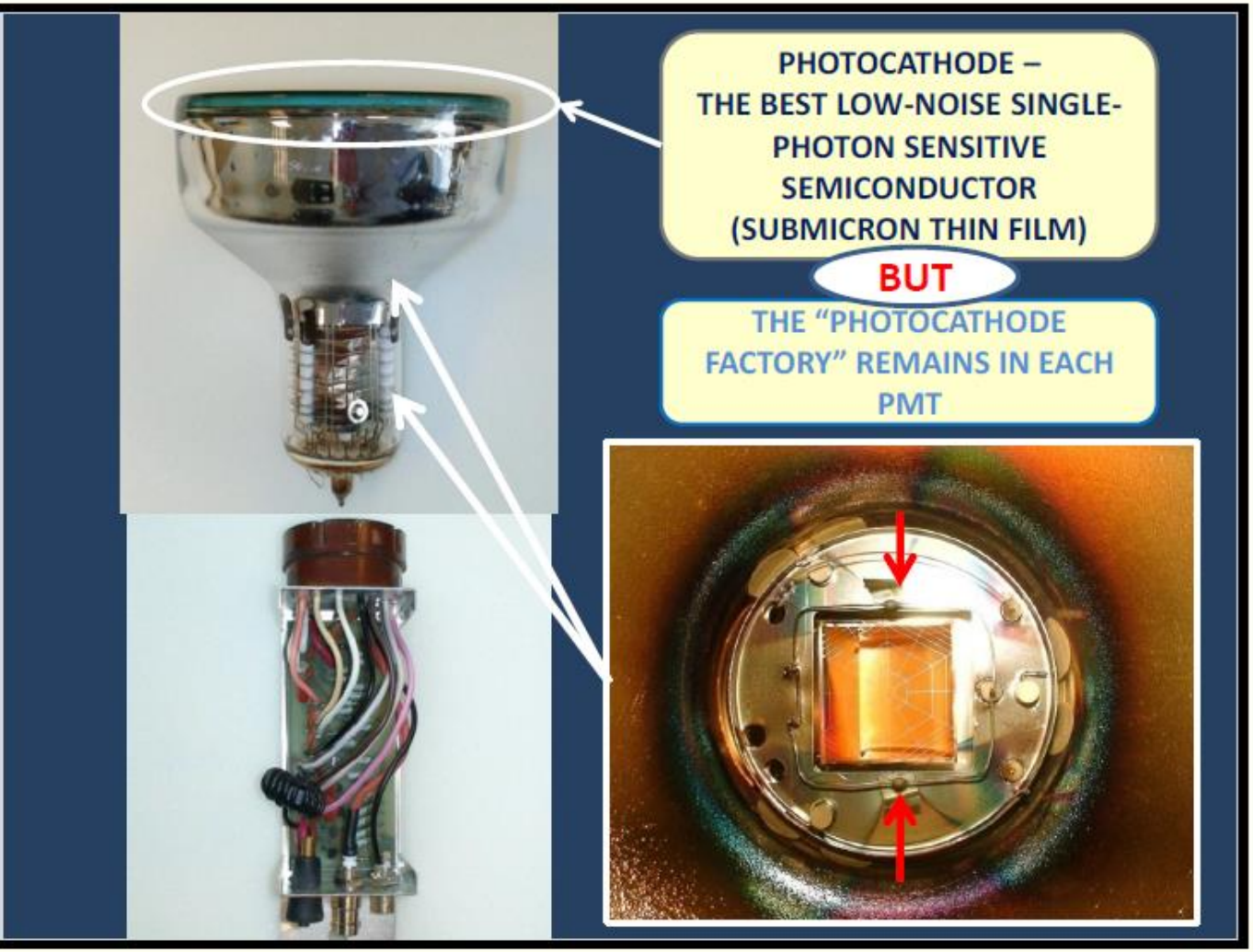
→ ABALONE CONSISTS OF ONLY 3 GLASS COMPONENTS

→ THE THREE COMPONENTS → IN - FINAL PRODUCT (PROTOTYPE) → OUT

→ FACILITY DESIGNED (since 2001) AND SUCCESSFULLY USED AT UC DAVIS

THE 80-YEAR-OLD PMT MANUFACTURE

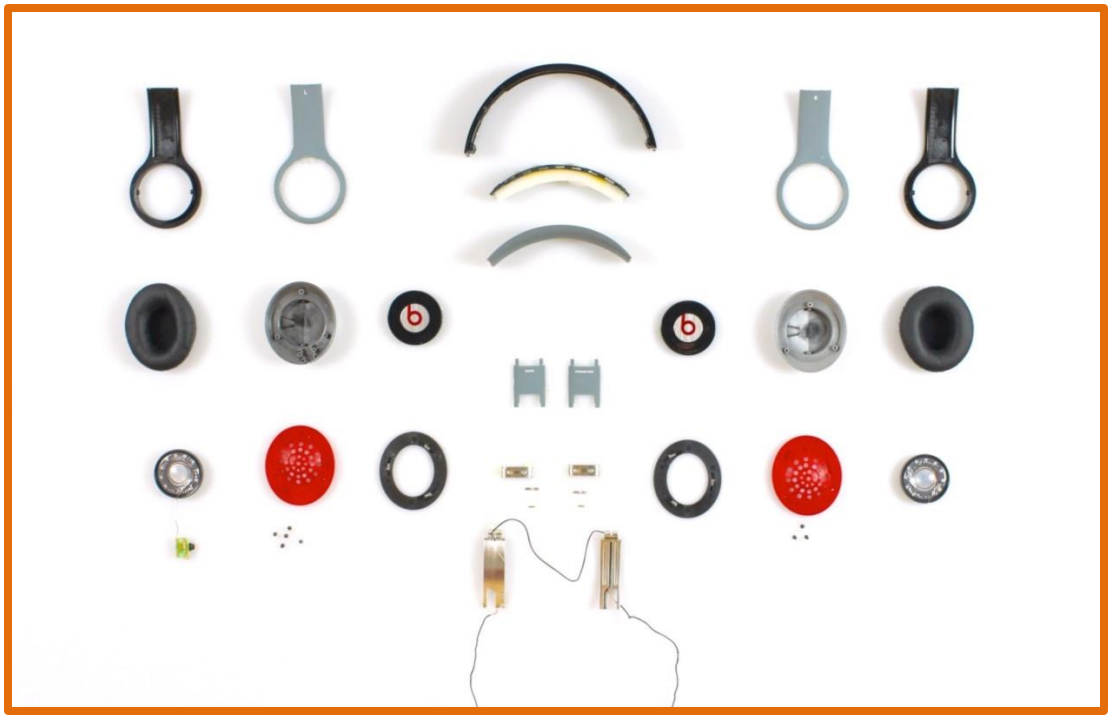
Neither the PMT (Photomultiplier Tube) configuration, nor its constructional materials or processes are suitable for mass production.



Metal-glass components are not suitable for modern mass-production by vacuum processing; the necessity of a long bakeout is one of the many reasons.

HUFFINGTON POST
June 23

Ben Einstein *"I was impressed, however, by the look and feel that was achieved with so few parts."*



PMT ANATOMY—ALL PARTS

HIGH COMPLEXITY AND HANDWORK

VACUUM

PHOTOCATHODE FACTORY
(Platinum beads and more)

>180 COMPONENTS
- ceramic
- glass
> 6 metals
-many fine meshes, handmade

> 400 CONNECTIONS
handmade

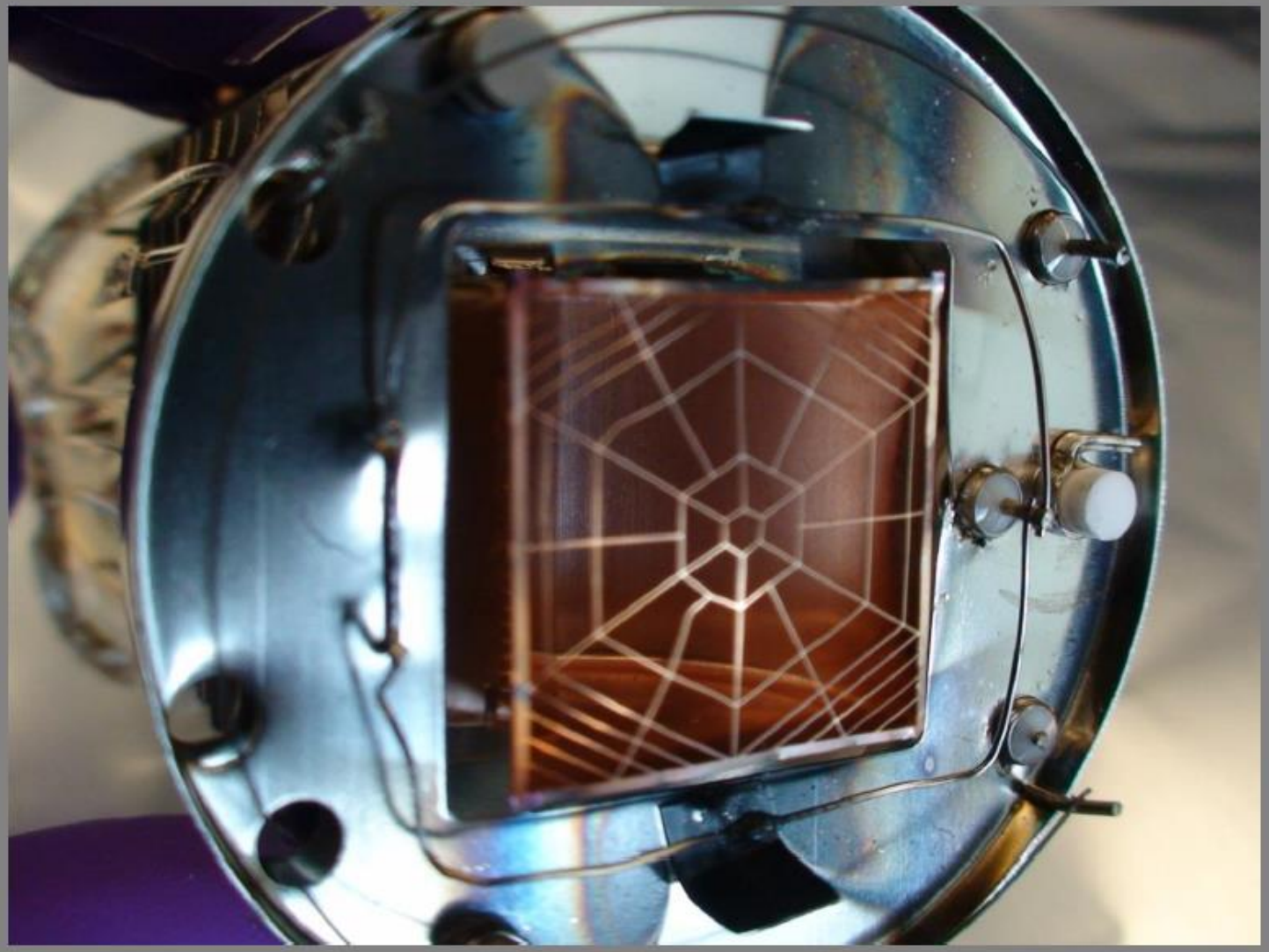
AIR

VOLTGE DIVIDER, CABLES, SUPPORT STRUCTURE, MU-METAL MAGNETIC SHIELD etc.

→ MODERN MASS PRODUCTION?

PMT ANATOMY—A DETAIL

HIGH COMPLEXITY AND SHAKY HANDWORK; NON-UNIFORM Sb-EVAPORATORS; TWO PLATINIUM BEADS



PMT COMPONENTS

ABALONE COMPONENTS

'PHOTOCATHODE FACTORY' -NONEXISTENT IN ABALONE (PHOTOCATHODE IS DEPOSITED IN THE PRODUCTION FACILITY)

DOME

BASE PLATE

WINDOWLET

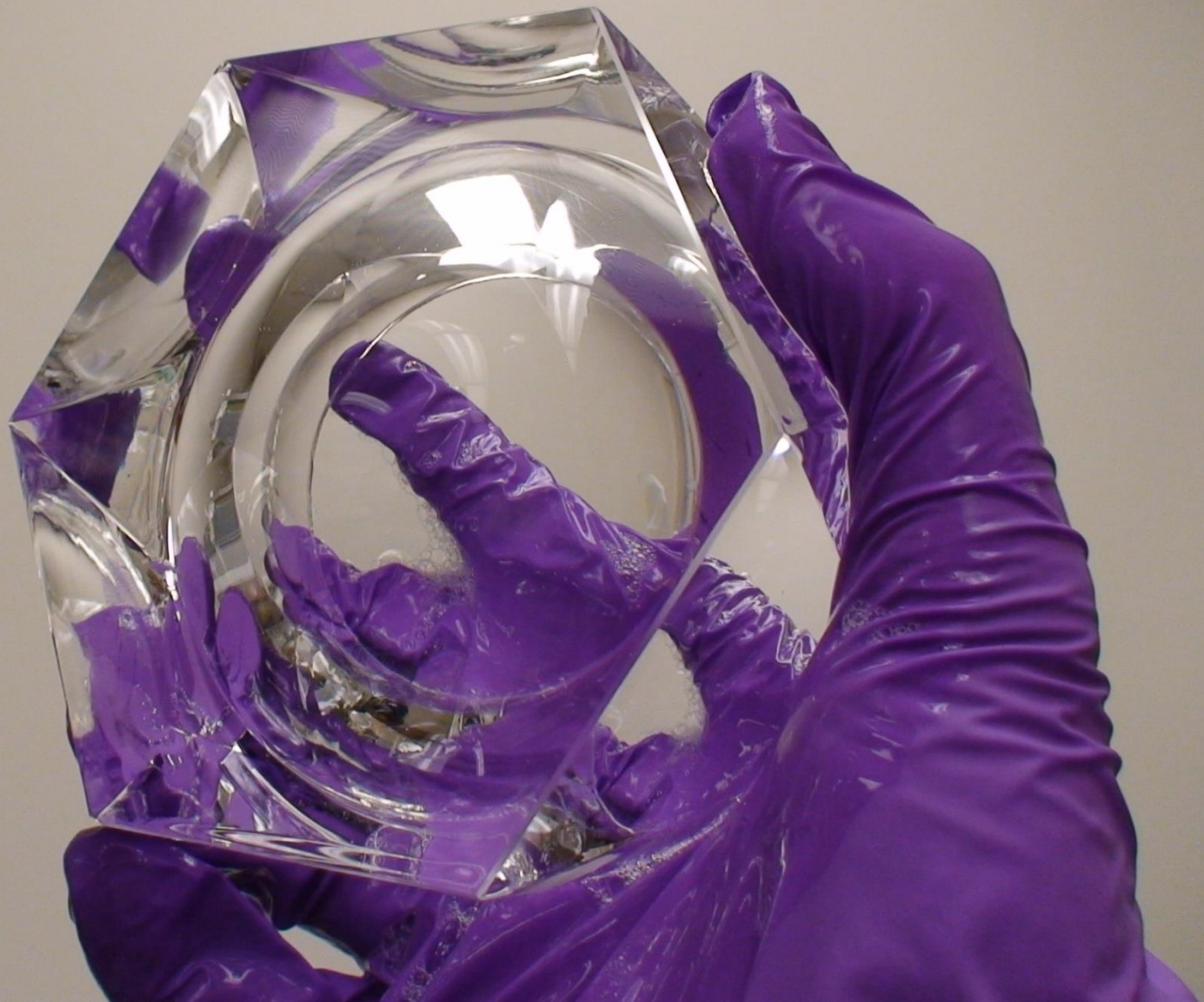
G-APD

VACUUM

AIR

All these PMT components are functionally replaced ONLY BY THE WINDOWLET & THE G-APD

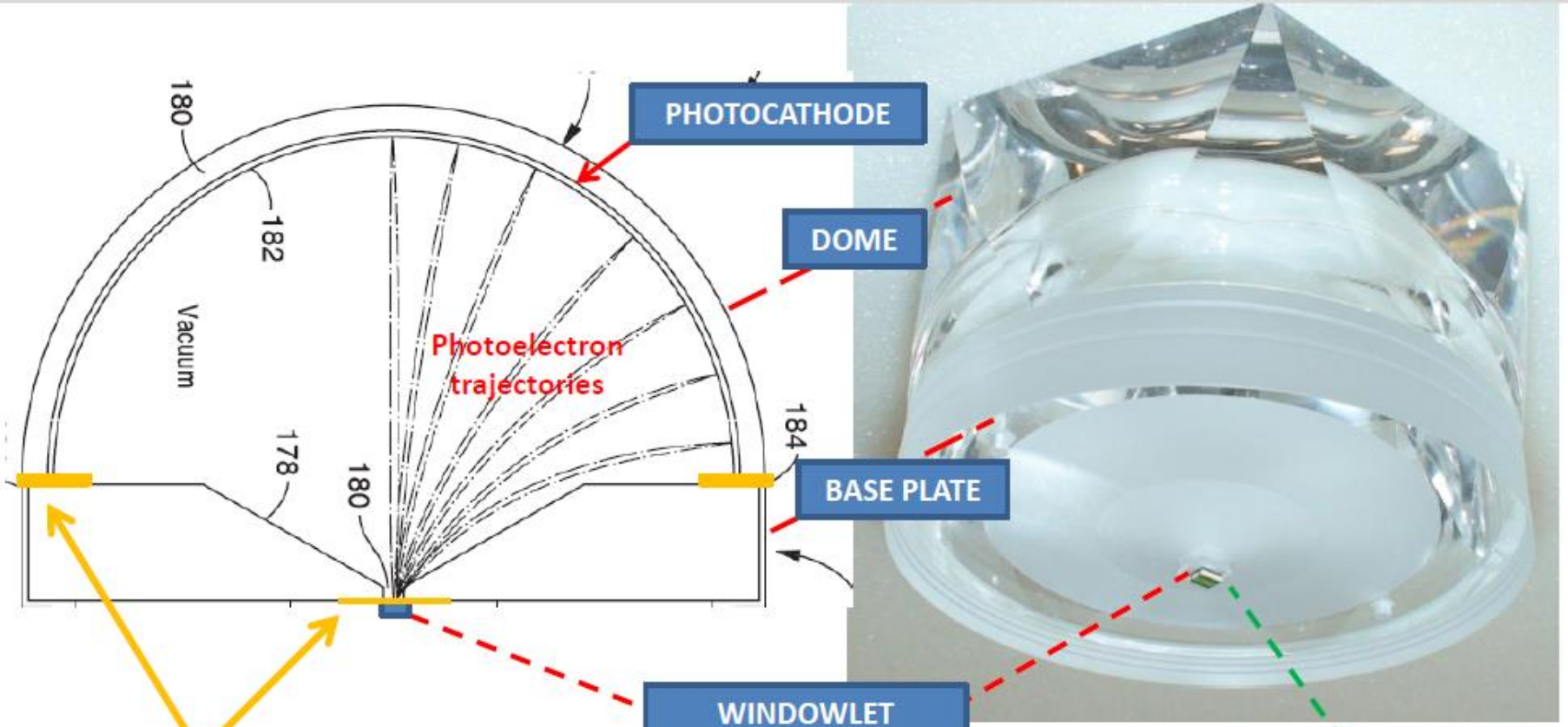
Patent No. 9,064,678



ABALONE PHOTOSENSOR

Patent No. 9,064,678

ABALONE FOCUSES ELECTRONS FROM THE PHOTOCATHODE TO THE 10,000 TIMES SMALLER SCINTILLATOR AREA ON THE WINDOWLET, ALLOWING FOR A VERY SMALL G-APD READOUT

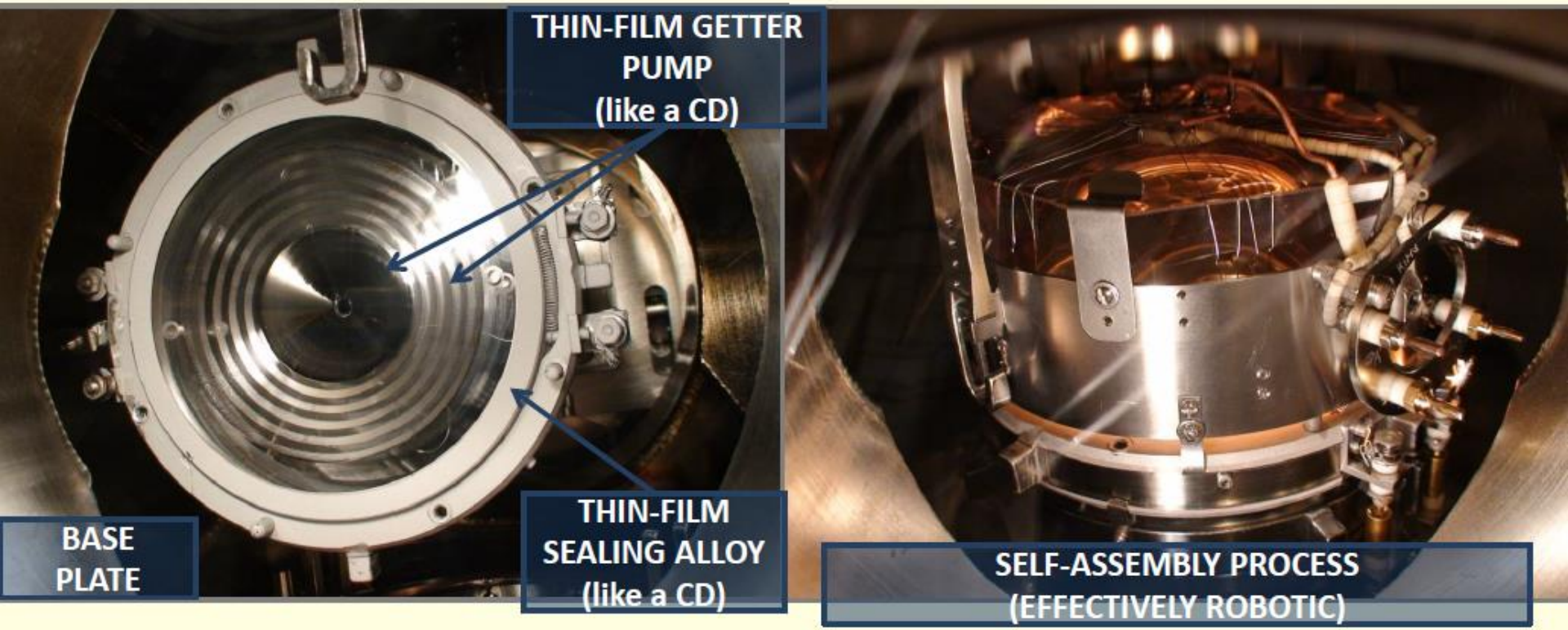


ABALONE TECHNOLOGY—THE KEY INVENTION

Patent No. 9,064,678

OXIDE-FREE GLASS SEALING METHOD:

***A new method for vacuum sealing of flat-panel photosensors*, Daniel Ferenc, Andrew Chang, Leah Johnson, Daniel Kranich, Alvin Laille, Eckart Lorenz. NIM A, 567 (2006)205–208.**



An alloy of particular properties is formed on selected flat glass surfaces by multi-metal thin-film deposition.

The same thin-films at the same time serve as the only two electrical feedthroughs.

ABALONE PHOTOSENSOR PROTOTYPE

Patent No. 9,064,678

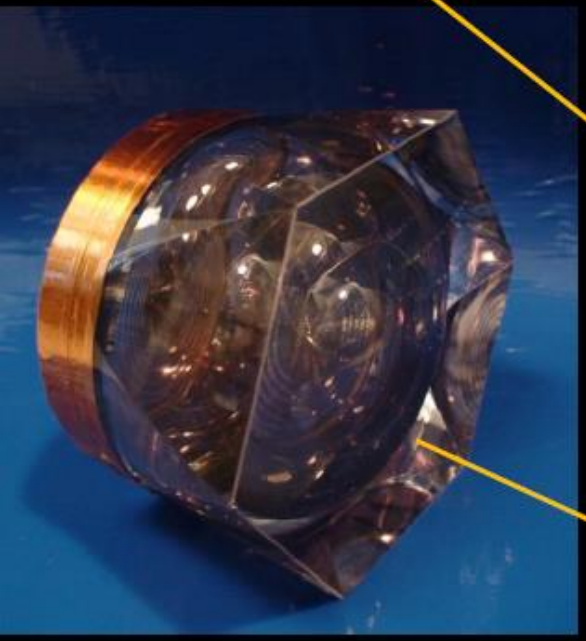
THE THREE GLASS COMPONENTS SEALED TOGETHER USING TWO ALLOY THIN-FILMS

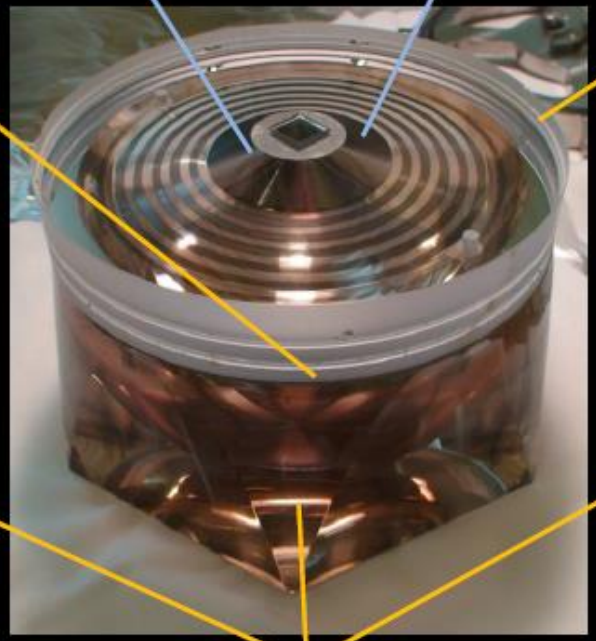
PROTOTYPE-13-05
(FUSED SILICA)

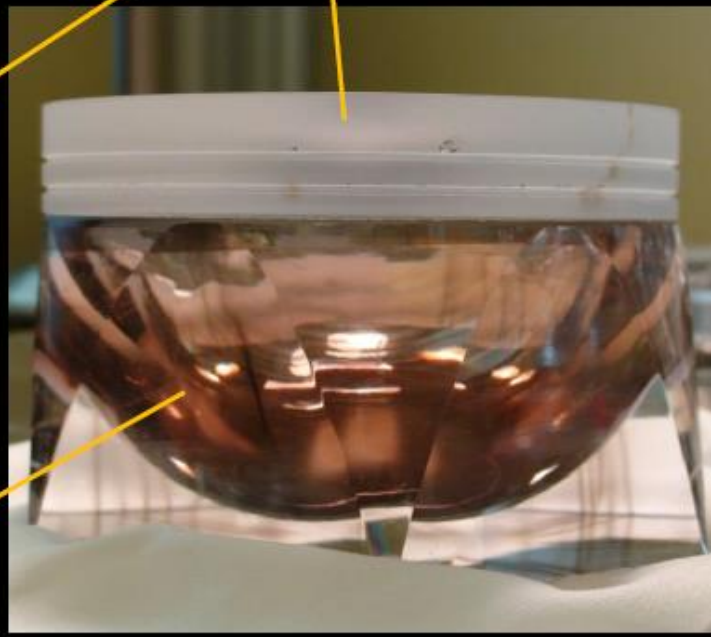
WINDOWLET
(LYSO)

THIN-FILM ALLOY
SEALS

BASE PLATE

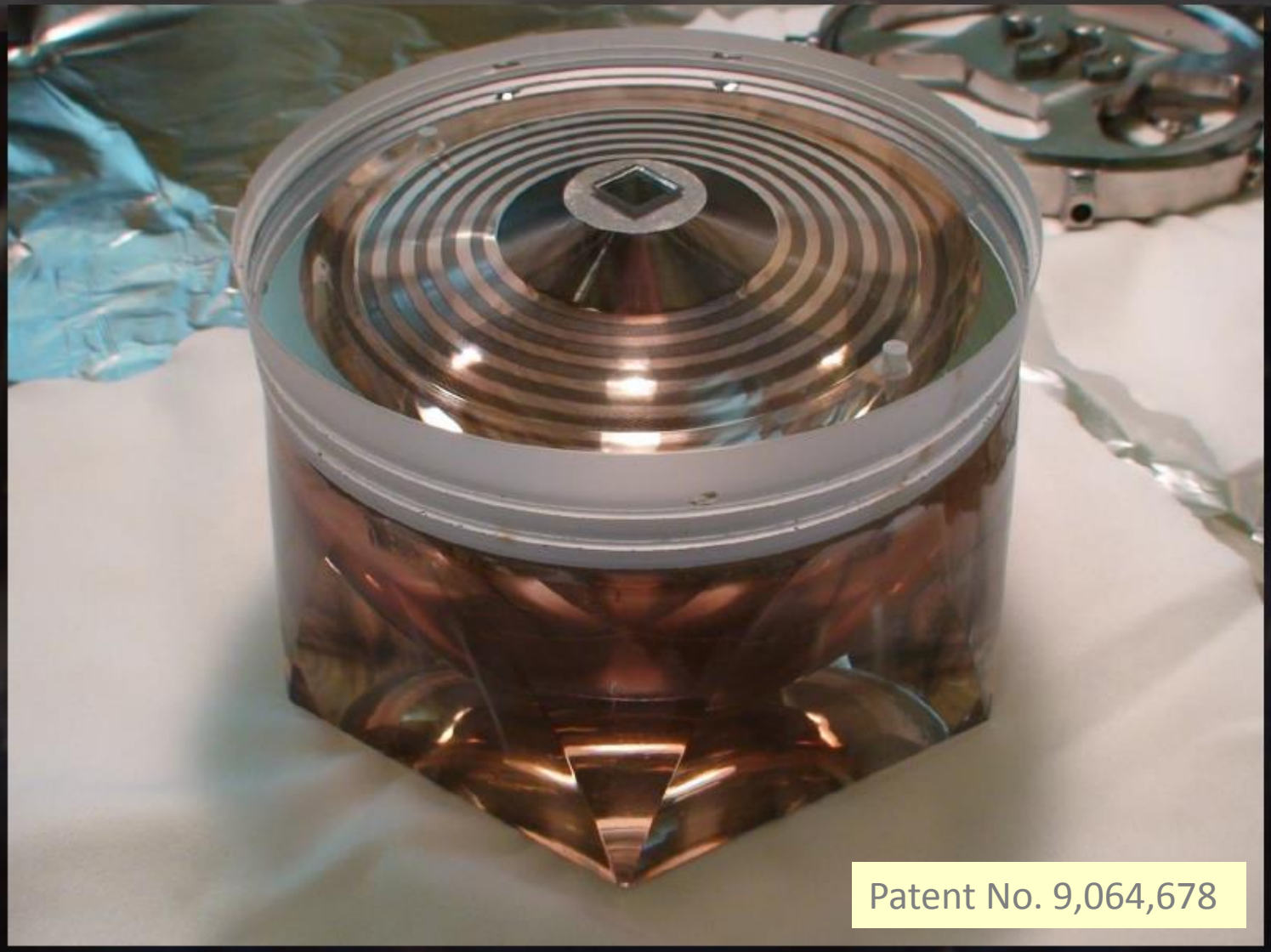






DOME

ABALONE APPLICATIONS – DARK-MATTER, DOUBLE-BETA DECAY…



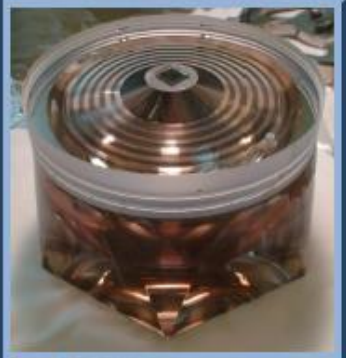
Patent No. 9,064,678

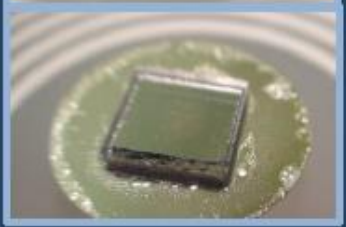
~ 100% ULTRAPURE FUSED SILICA + THIN FILMS OF SELCTED MATERIALS + SPECIAL-G-APD

➔ **UNBEATABLY** LOW LEVEL OF RADIOACTIVITY ➔

ABALONE PHOTOSENSOR PROTOTYPE

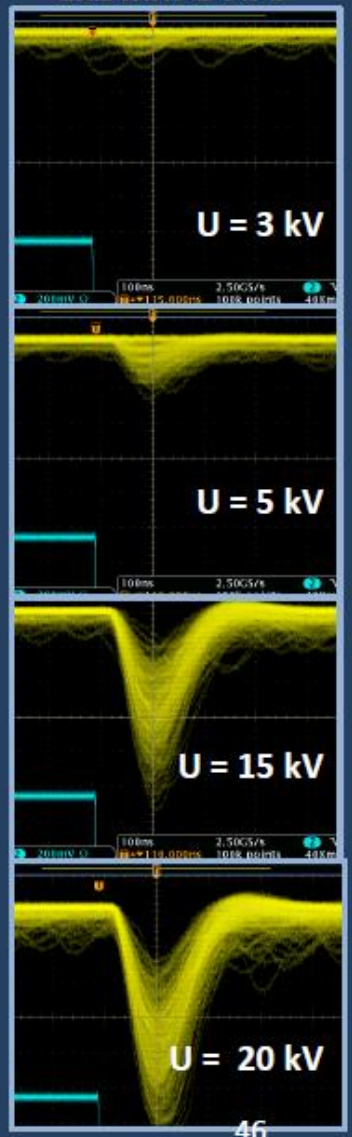
PROTOTYPE-13-05: PHOTOS TAKEN JUST AFTER THE ASSEMBLY; IMMEDIATE TEST RESULTS



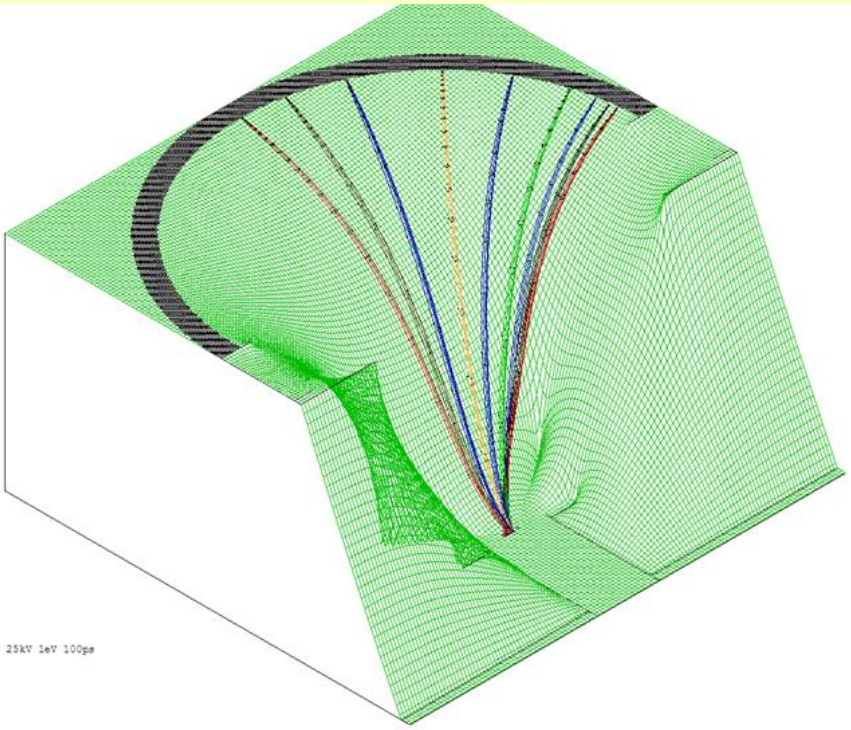


Patent No. 9,064,678

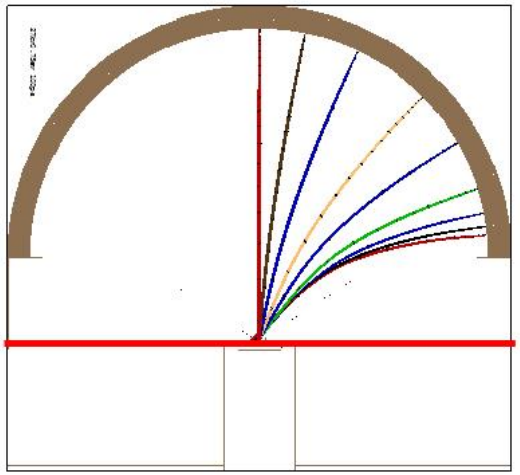
1x1 mm G-APD



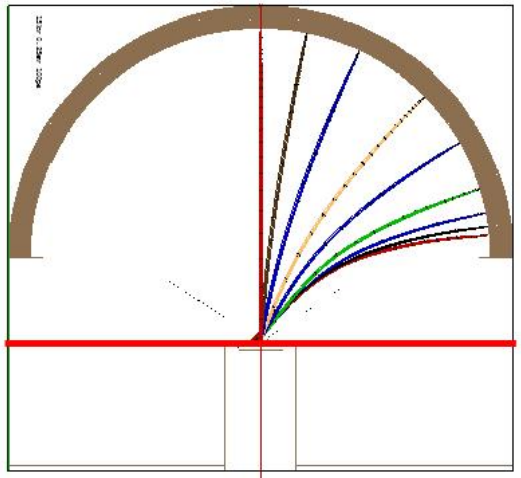
Patent No. 9,064,678 and patent pending PCT/US15/031188



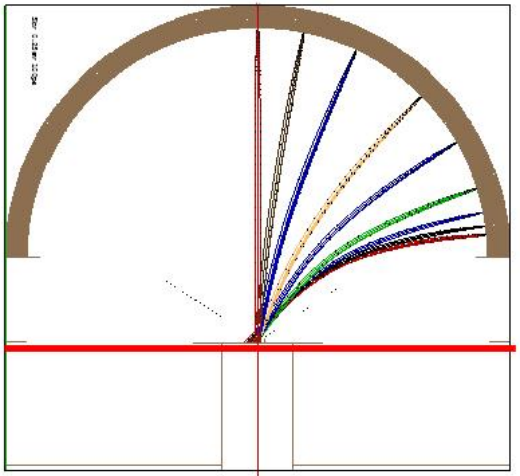
U = 27 kV



U = 15 kV

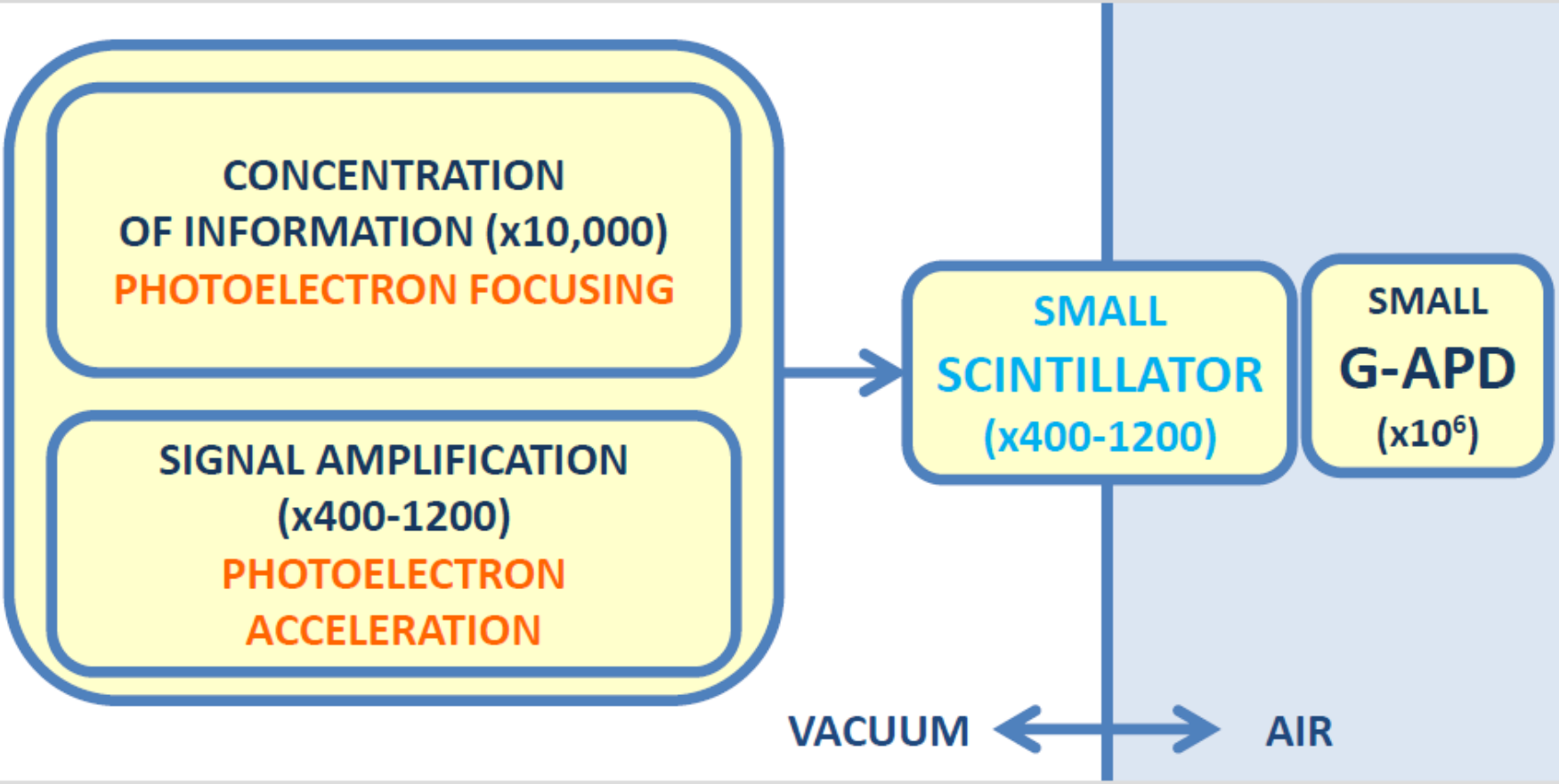


U = 5 kV



ABALONE PHOTOSENSOR—OPERATION PRINCIPLE (LIGHT AMPLIFIER)

ABALONE FOCUSES ELECTRONS FROM THE PHOTOCATHODE TO THE 10,000 TIMES SMALLER SCINTILLATOR AREA ON THE WINDOWLET, ALLOWING FOR A VERY SMALL AND CHEAP G-APD READOUT UNIT



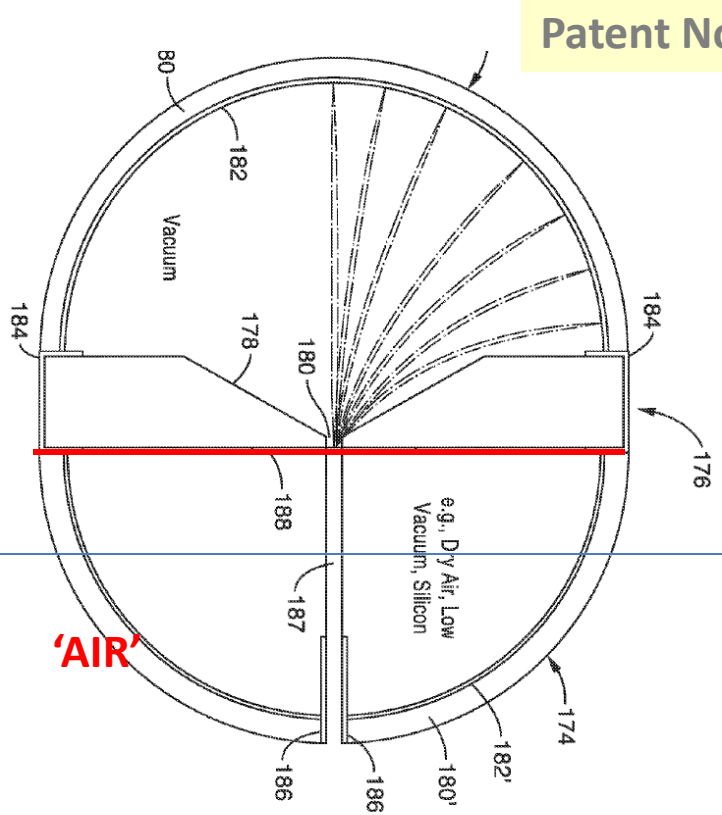
D. Ferenc, D. Kranich, A. Laille, E. Lorenz, "Novel Light Amplifier Concept," Nuclear Instruments and Methods in Physics Research A567(2006)166-171.

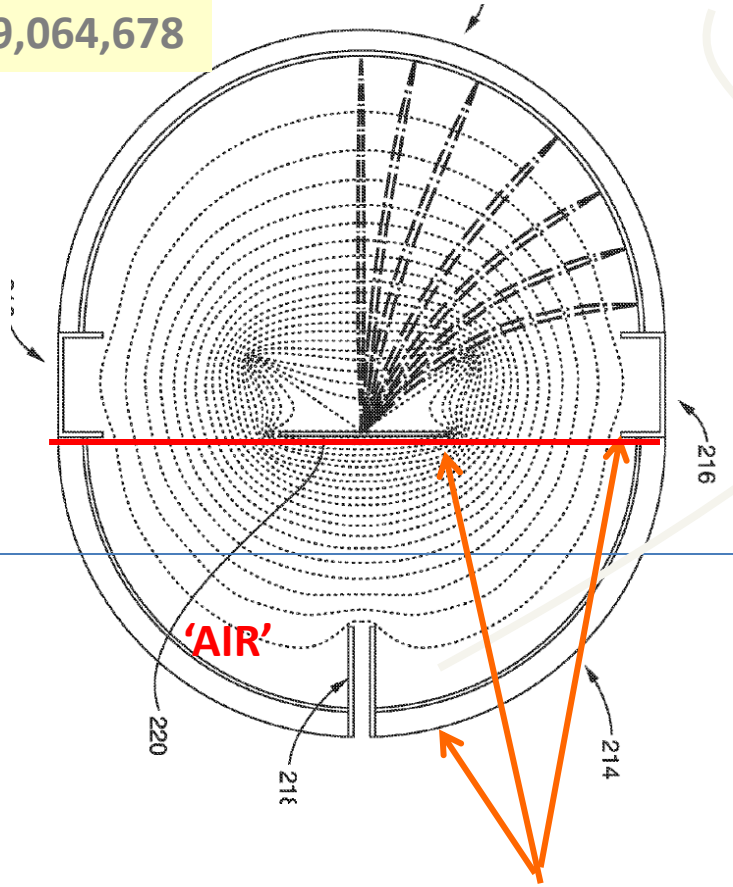
E. Lorenz and D. Ferenc, "A new Readout of large area Smart Photomultipliers by Geiger-mode APDs," Nuclear Instruments and Methods in Physics Research A572(2007)434-436.

Daniel Ferenc and Eckart Lorenz, "Novel photosensors for neutrino detectors and telescopes, " Earth Moon Planet (2007) 100:241–257. Also check older literature on QUASAR , SMART-PMT, image intensifiers.

ABALONE FOCUSING IS ARRANGED
"BEHIND THE (VACUUM) SCENES" (i.e. in the 'AIR')

Patent No. 9,064,678





THE ELECTRIC FIELD PENETRATES GLASS ☺

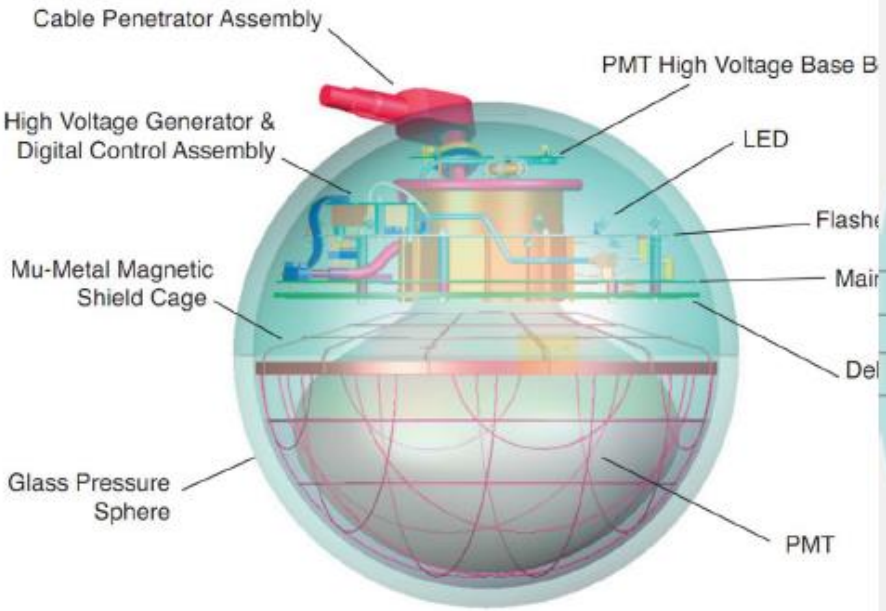
Conductive surfaces OUTSIDE THE VACUUM (their dimensions make the focusing lens)

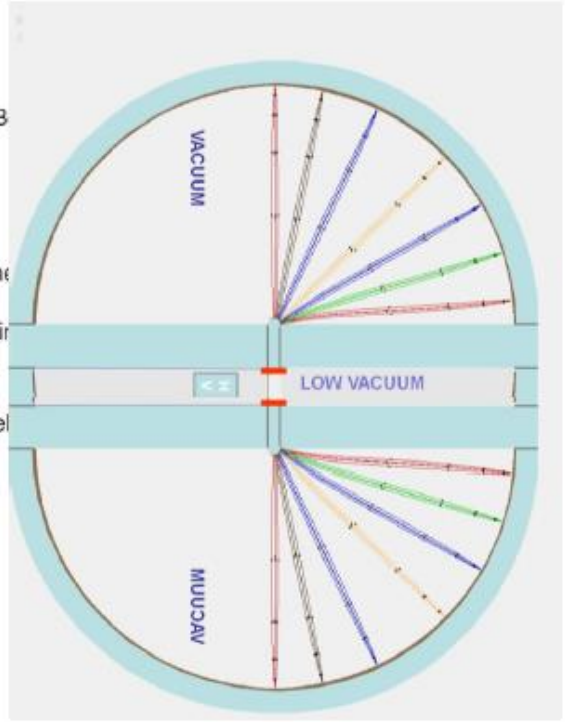
ABALONE APPLICATIONS – NEUTRINO PHYSICS & ASTROPHYSICS

Patent No. 9,064,678

IceCube OPTICAL MODULE

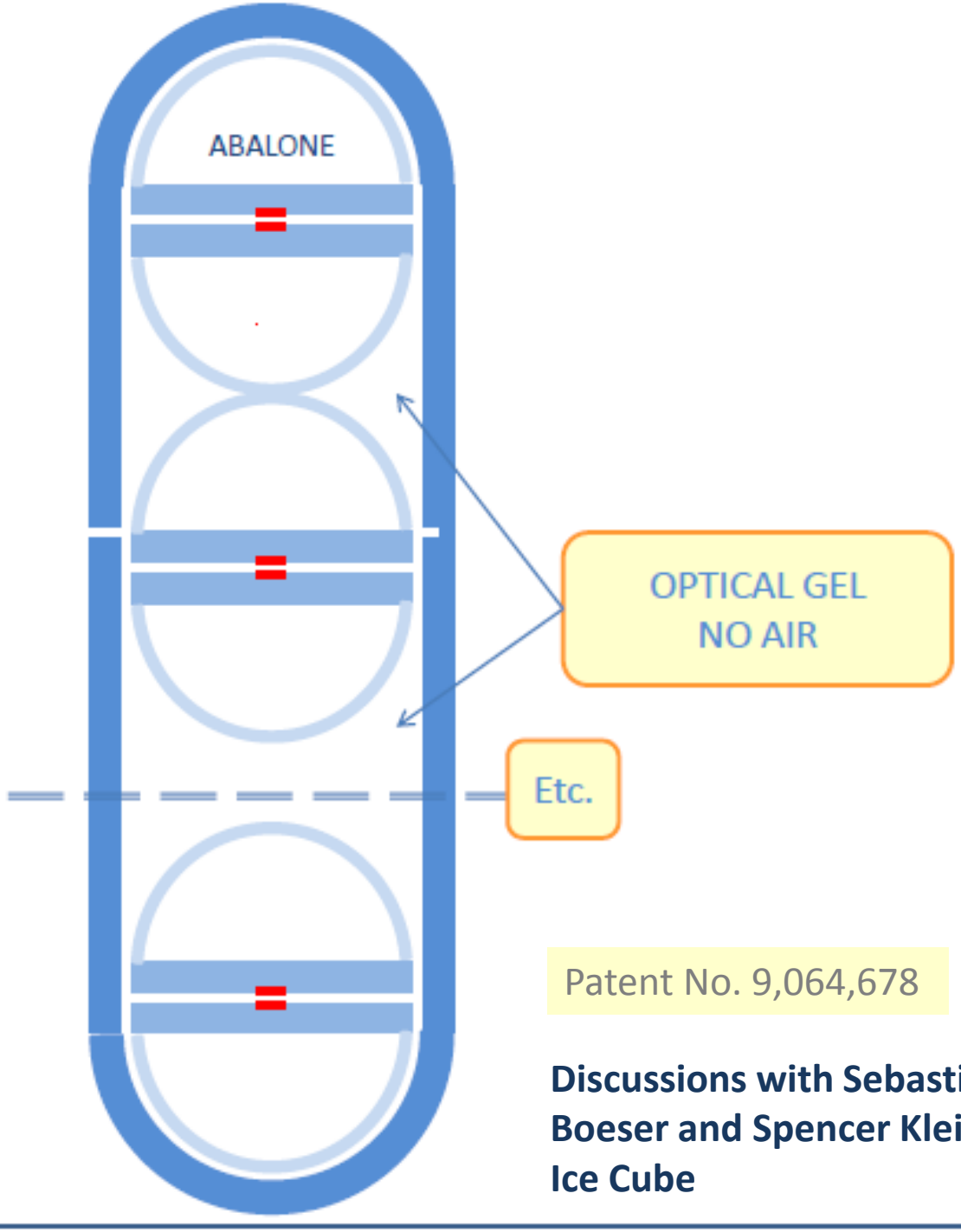
IceCube's DREAM





→FOR THE LARGE ARRAY OF NEUTRINO PHYSICS EXPERIMENTS, ABALONE OFFERS SUPERIOR PERFORMANCE ALONG WITH SIGNIFICANT COST REDUCTION, SIMPLIFICATION AND ROBUSTNESS

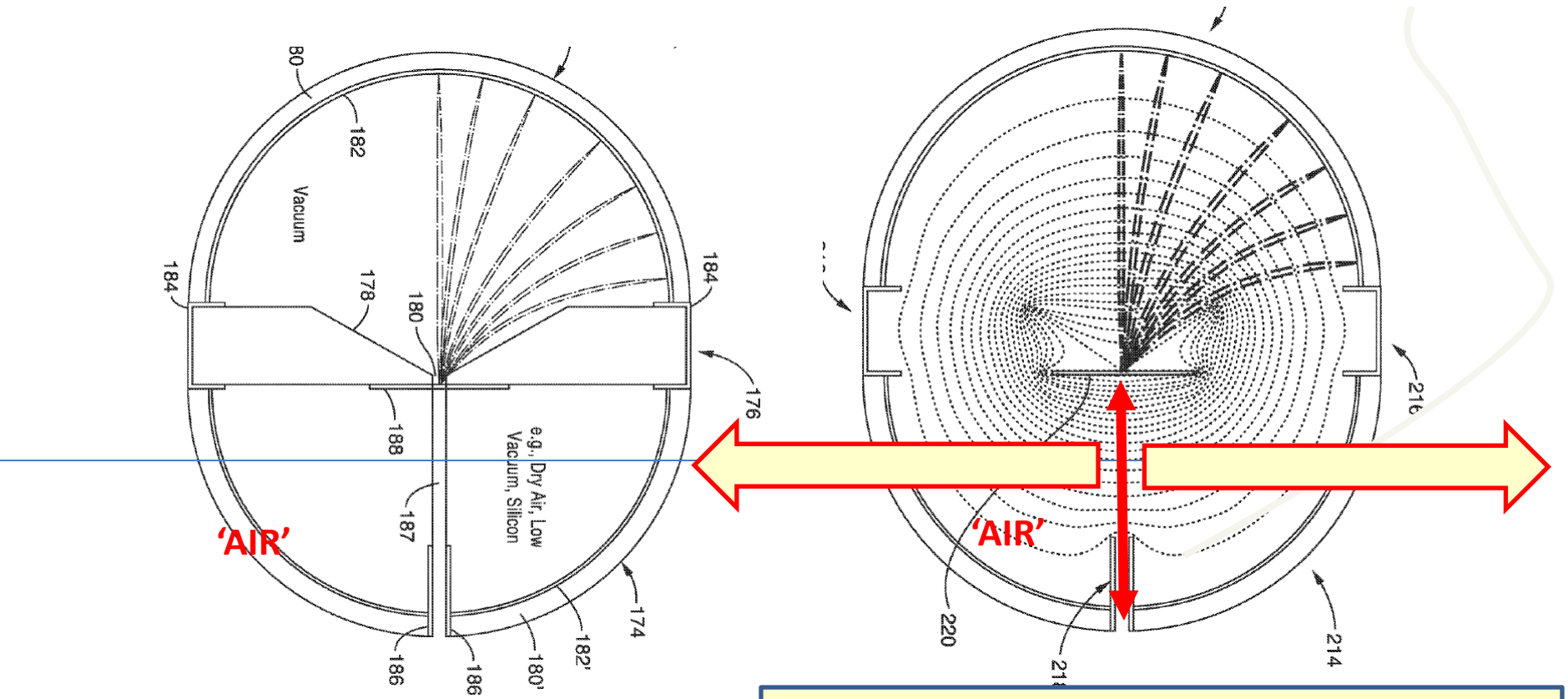
→FOR INSANCE, THE PRESSURE SPHERES FOR THE ICE-CUBE EXPERIMENT AT THE SOUTH POLE MAY BE USED DIRECTLY AS ABALONE DOMES (AFTER SOME MODIFICATION)



Patent No. 9,064,678

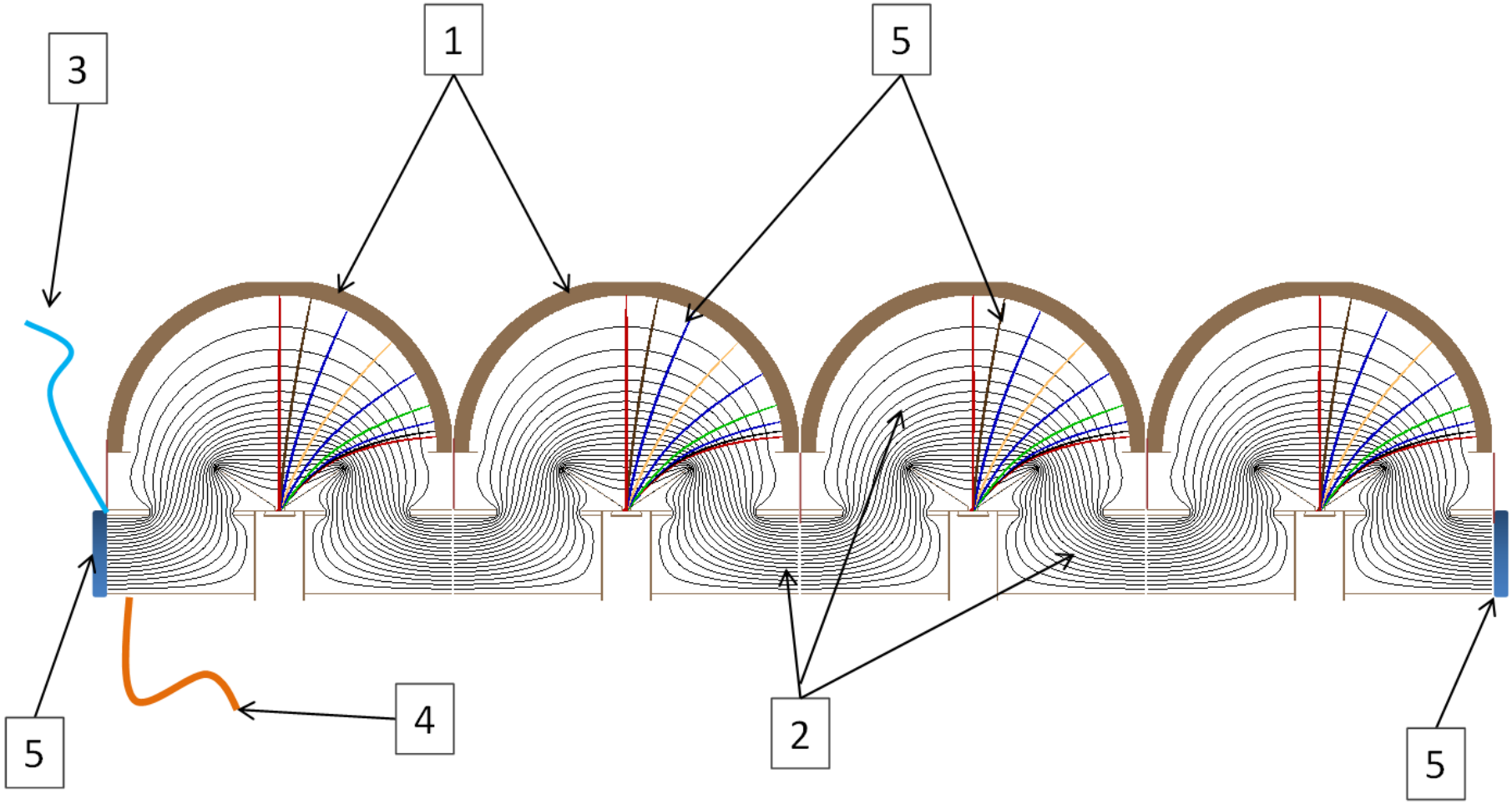
Discussions with Sebastian Boeser and Spencer Klein Ice Cube

ABALONE FOCUSING IS ARRANGED
"BEHIND THE (VACUUM) SCENES" (i.e. in the 'AIR')



CUT AND "EXPORT" THE FIELD LINES TO THE NEIGHBORING UNITS IN A MATRIX

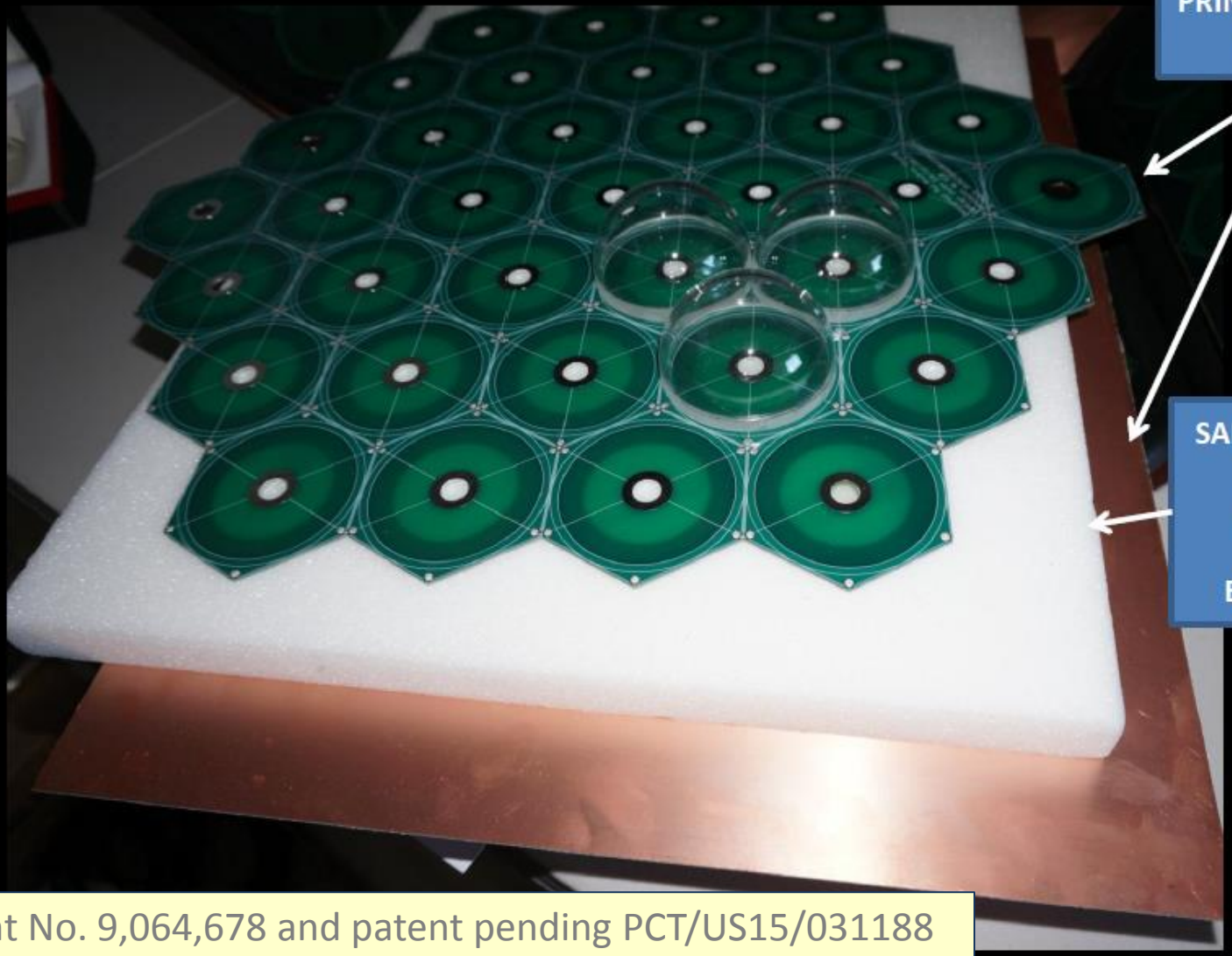
Patent No. 9,064,678 and patent pending PCT/US15/031188



Patent No. 9,064,678 and patent pending PCT/US15/031188

THE ANATOMY OF ABALONE FLAT PANELS

THE SMART SANDWICH

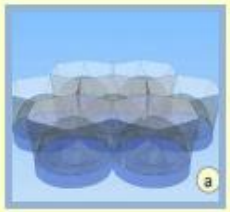


Patent No. 9,064,678 and patent pending PCT/US15/031188

→ **MOST COMMON, ULTIMATELY CHEAP BUILDING MATERIALS AND PROCESSES**

ABALONE FLAT-PANEL RADIATION DETECTORS

INTEGRATION: 'SMART SANDWICH' BOARD



SANDWICH: PCB + FOAM + PCB

- THIN & LIGHT
- RIGID
- NO CABLES
- WINSTON CONES - SEAMLESS PHOTOSENSITIVE SURFACE
- MODULAR

THIN 3-D CUSTOM-SHAPED MODULAR SHELL STRUCTURES

ABALONE-PET SCANNER

PHYSICS

NUCLEAR SECURITY

Patent No. 9,064,678 and patent pending PCT/US15/031188

ABALONE TECHNOLOGY - APPLICATIONS

MEDICAL IMAGING

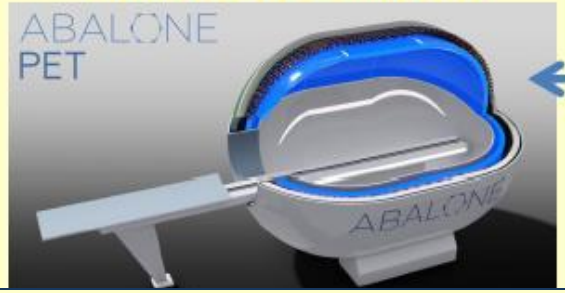
NUCLEAR SECURITY

PHYSICS RESEARCH

FLAT-PANEL RADIATION DETECTORS

NEUTRINO DETECTORS

ULTRASENSITIVE ABALONE-PET SCREENING FOR EARLY DETECTION OF CANCER



THIN 3-D CUSTOM-SHAPED, MODULAR

DARK MATTER SEARCH → ABALONE ~100% quartz

Patent No. 9,064,678 and patent pending PCT/US15/031188

CUSTOM-SHAPED RADIATION DETECTOR SHELLS

Patent No. 9,064,678 and patent pending PCT/US15/031188

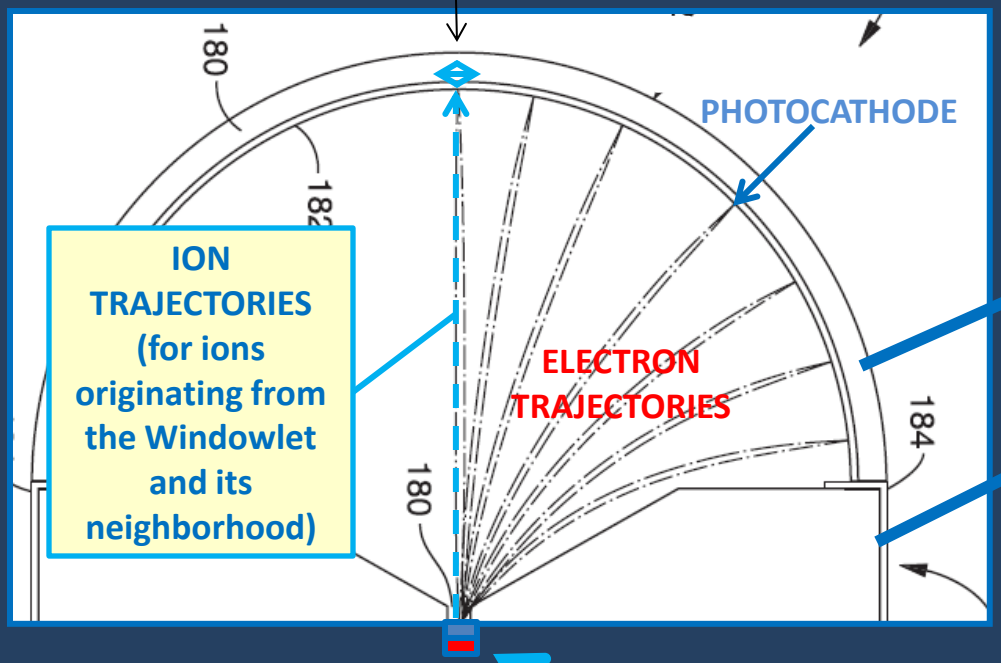
ABALONE flat-panel boards may form robust, rigid and even waterproof building blocks, ideal for various large-area detectors, such as PET scanners (see following slides), detectors for homeland security, physics and astrophysics research.

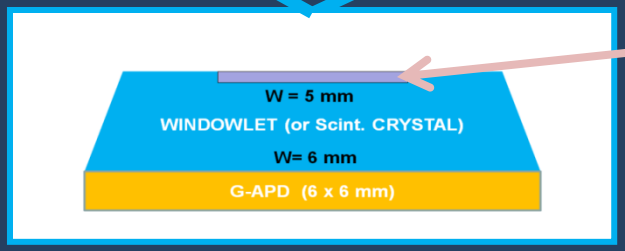
➔SELF-SUPPORTING, LIGHTWEIGHT, MODULAR, CUSTOM 3-D SHAPES

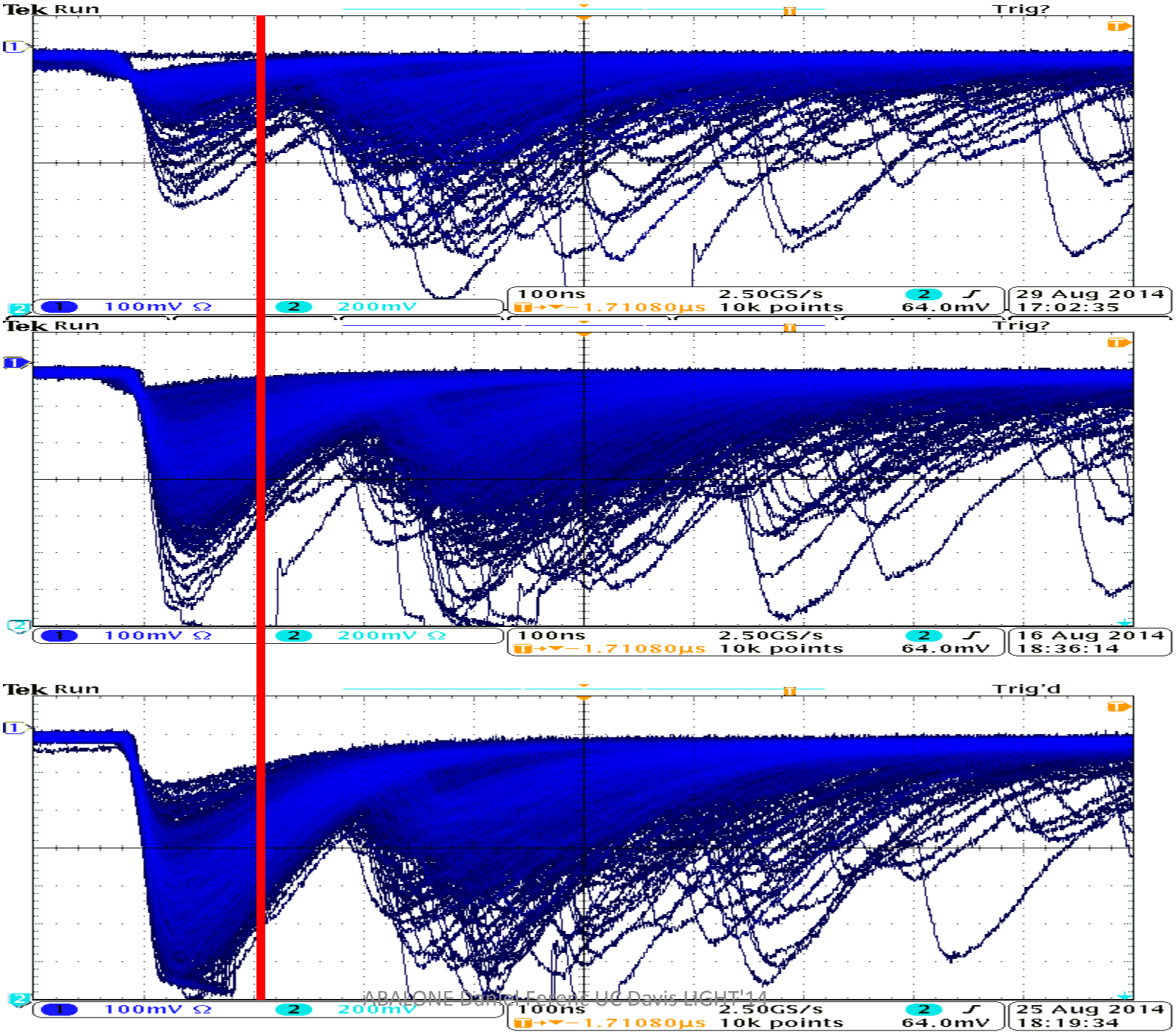
➔HV & READOUT DISTRIBUTED WITHIN THE PANEL, NO CABLES

POSITIVE IONS - AFTERPULSING

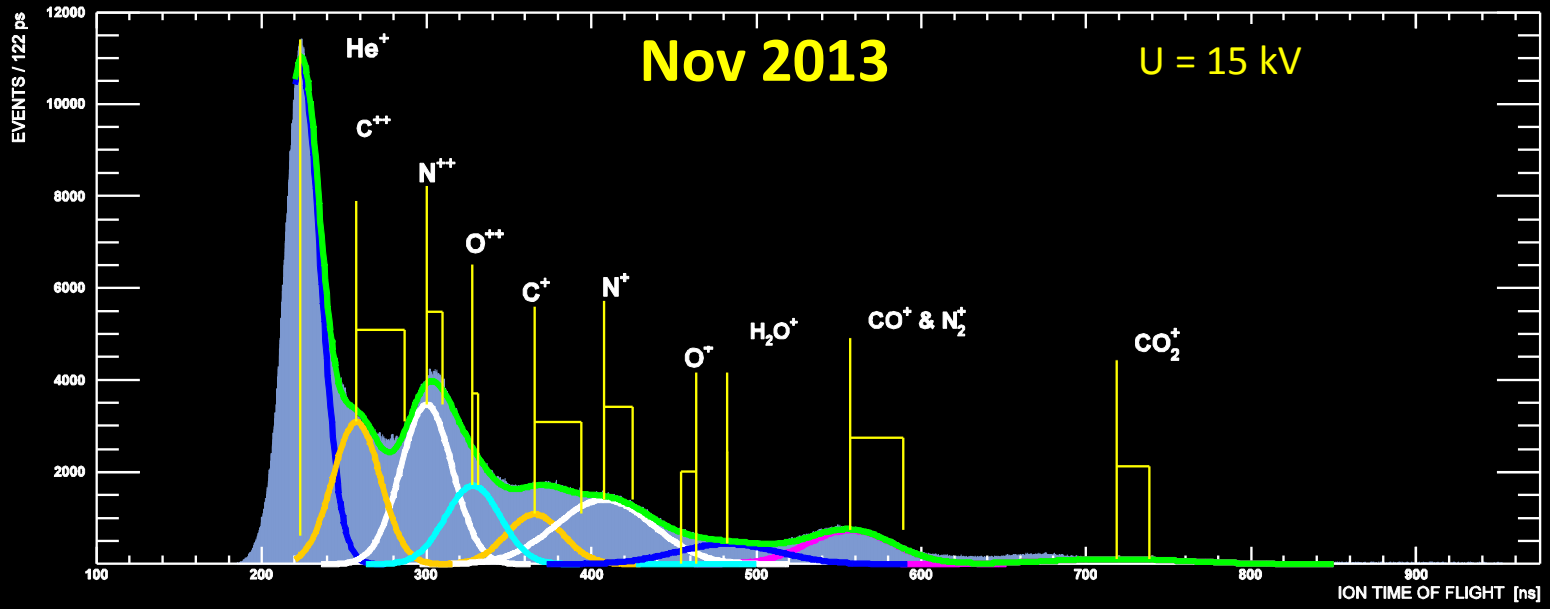
ion hit area ~4 mm

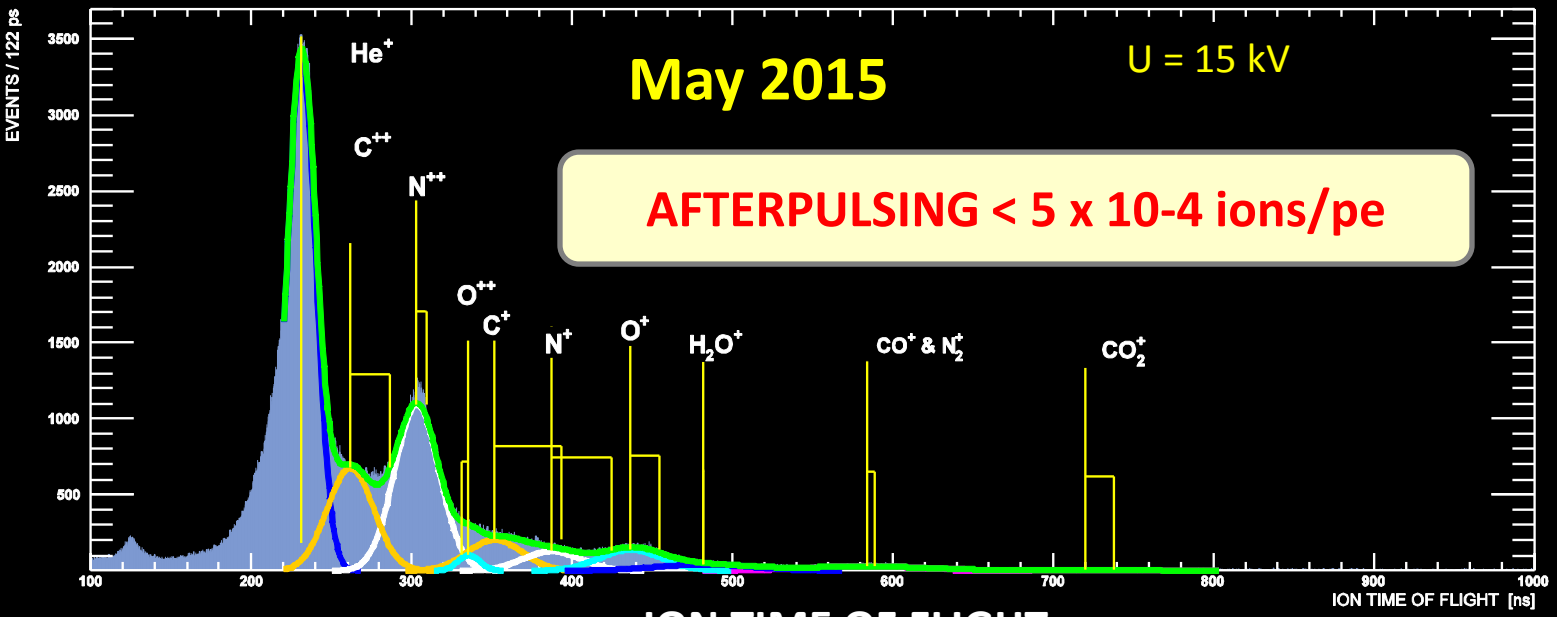






ABALONE SELFIES: TIME-OF-FLIGHT MASS SPECTROSCOPY





AFTERPULSING < 5 x 10-4 ions/pe

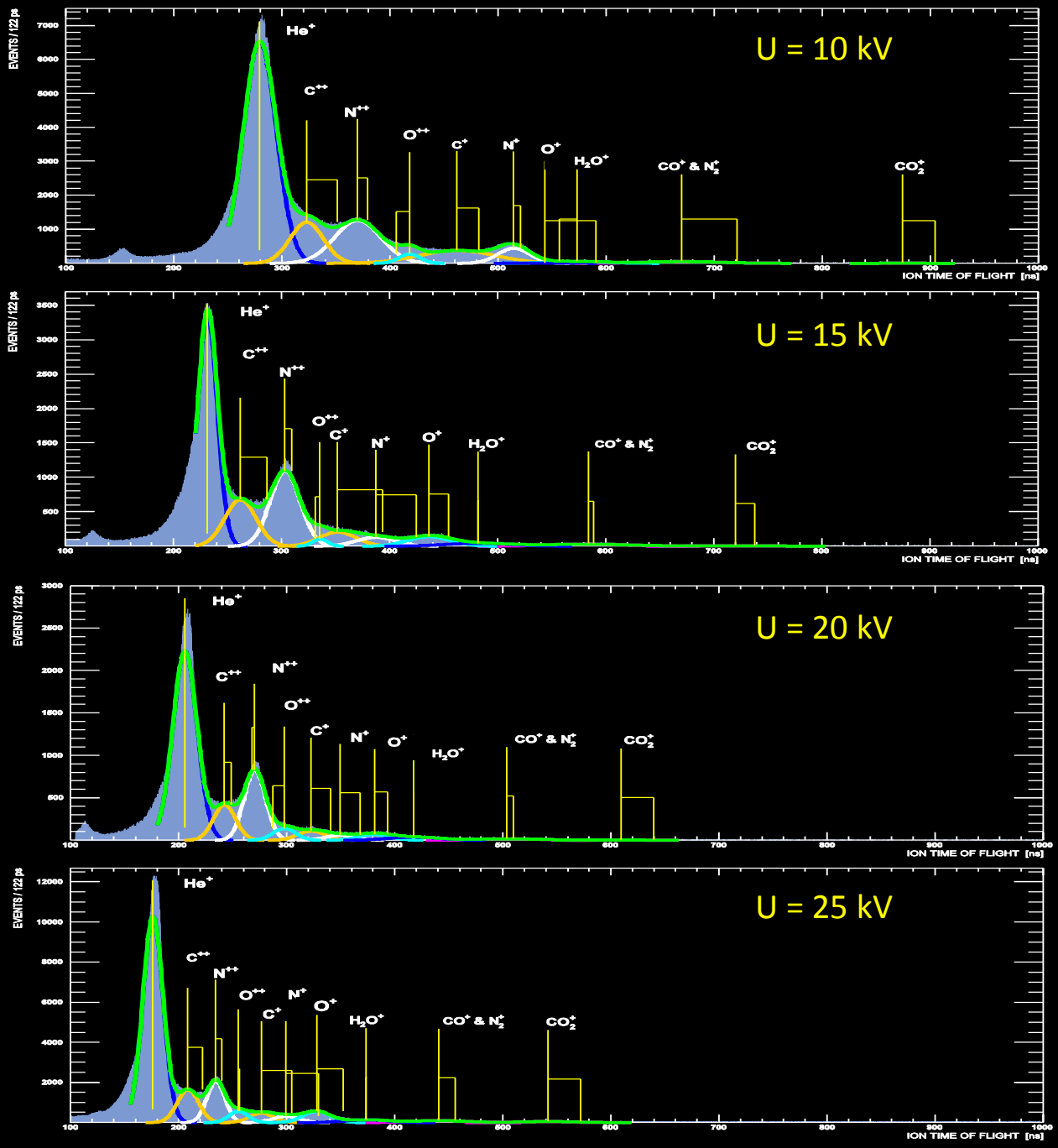
ION TIME OF FLIGHT

SELF-VACUUM PUMPING:

A. CHEMI-SORPTION

B. PHYSI-SORPTION

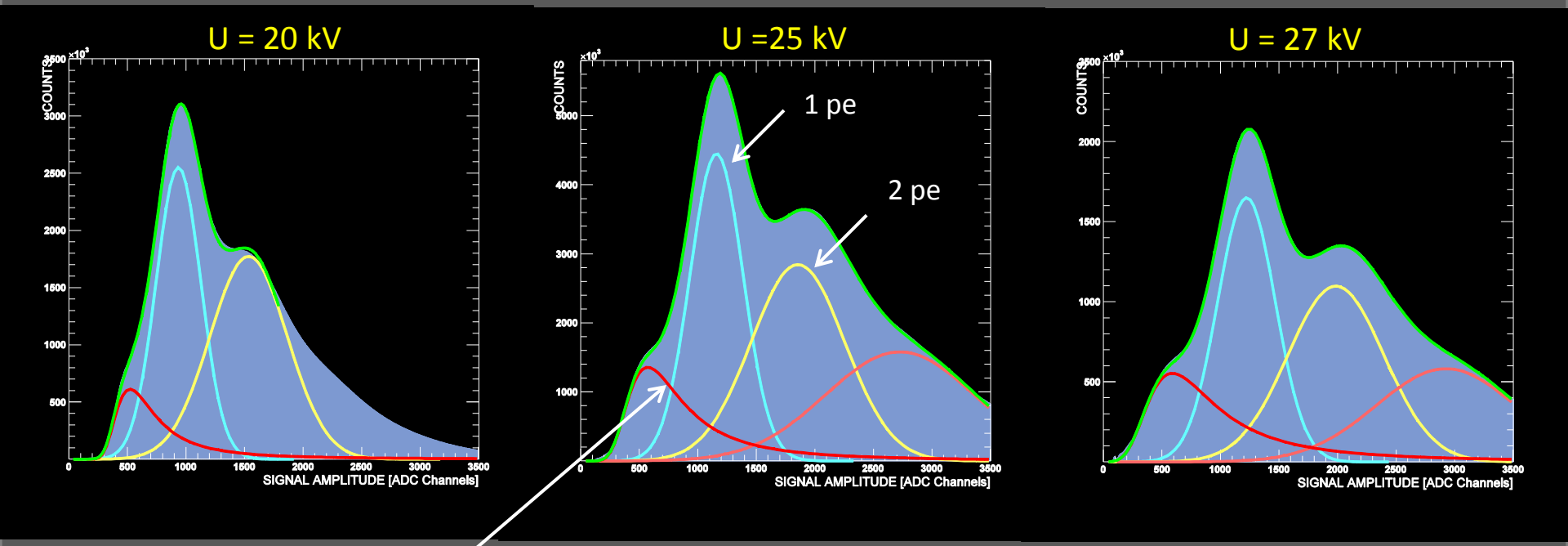
C. ION IMPLANTATION



TOF ~ $U^{-1/2}$

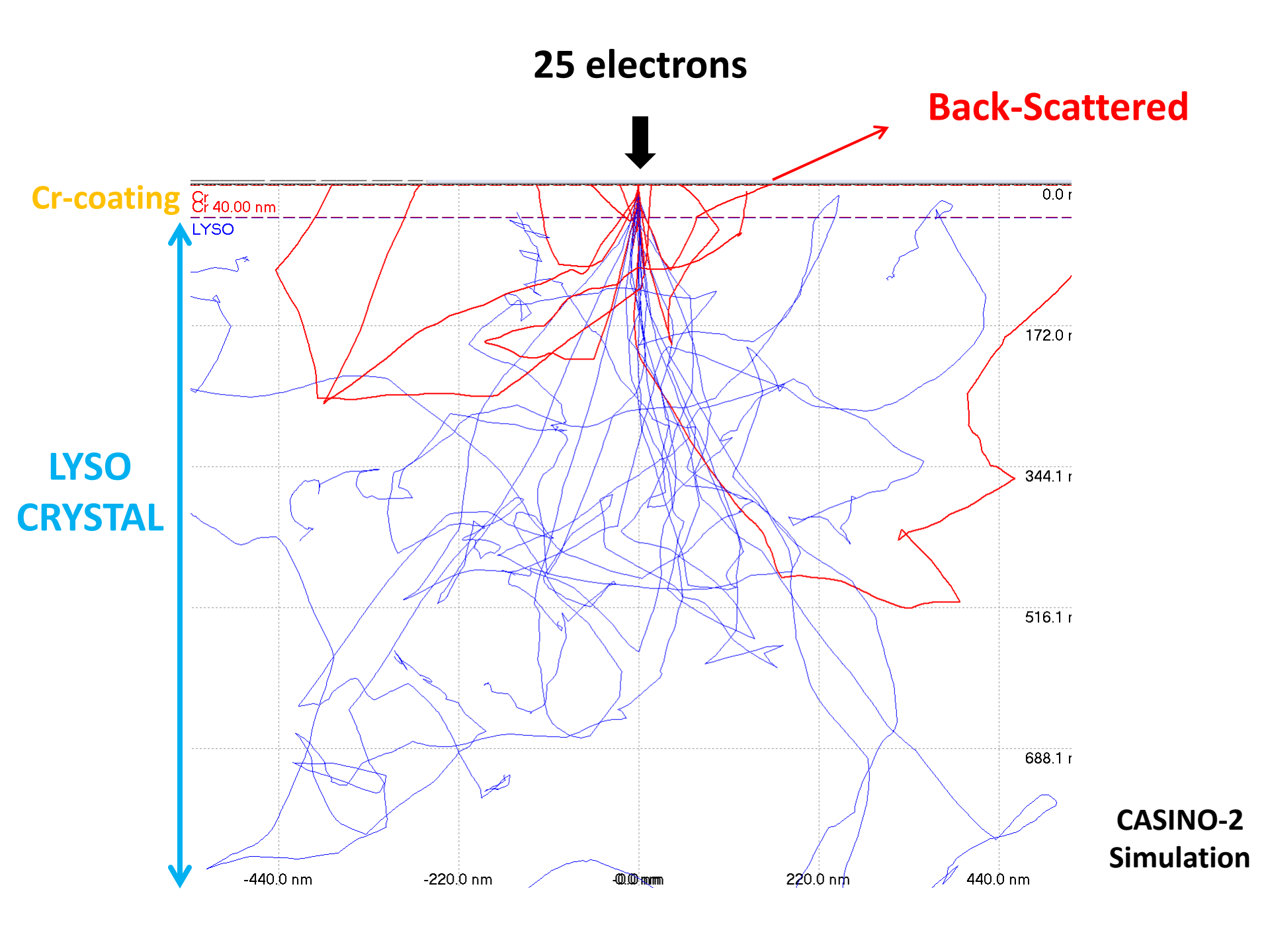
ION TIME OF FLIGHT

SINGLE PHOTONS

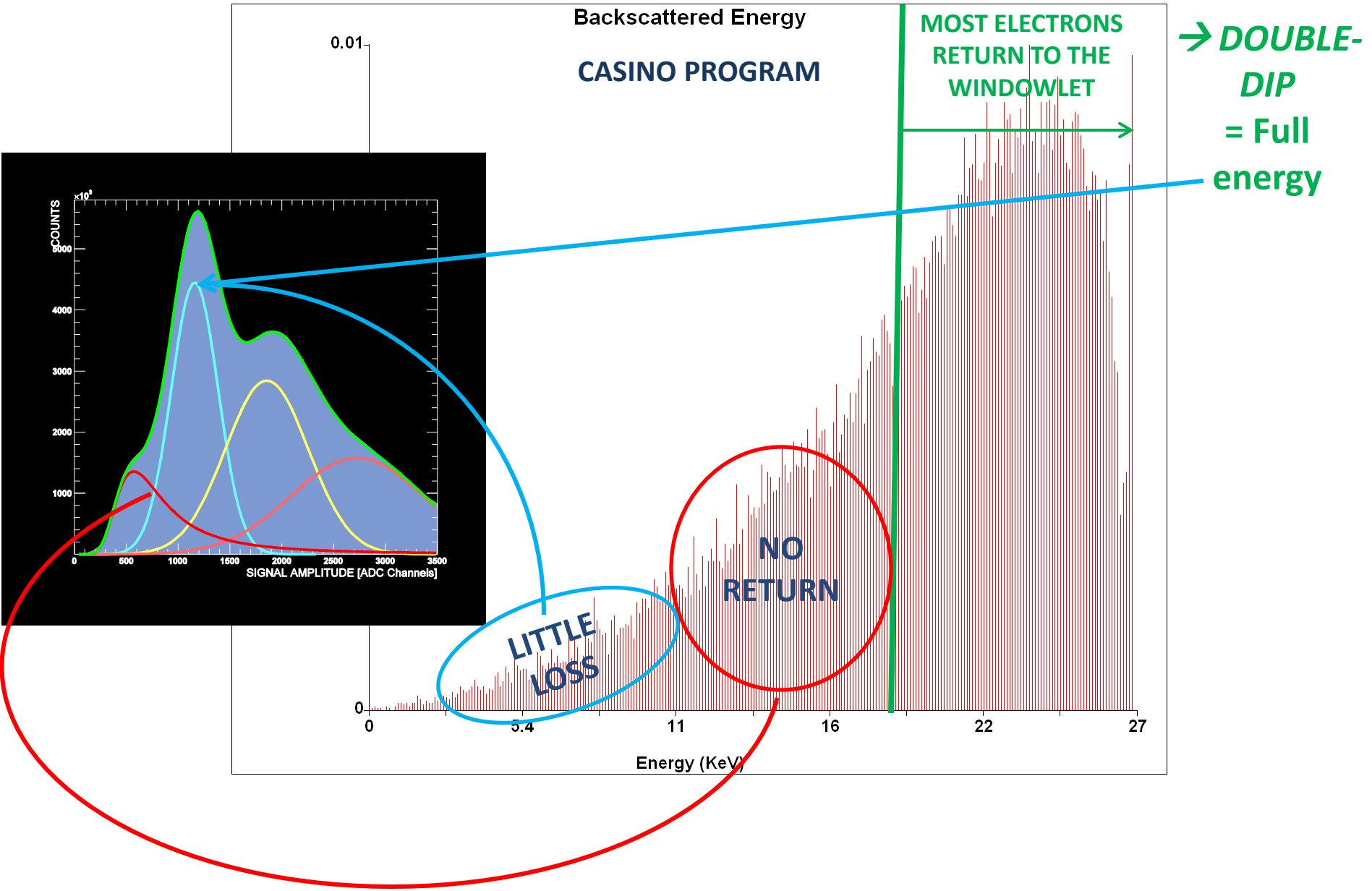


SIGNAL AMPLITUDE

Back-Scattered photo-electrons (non-returning)

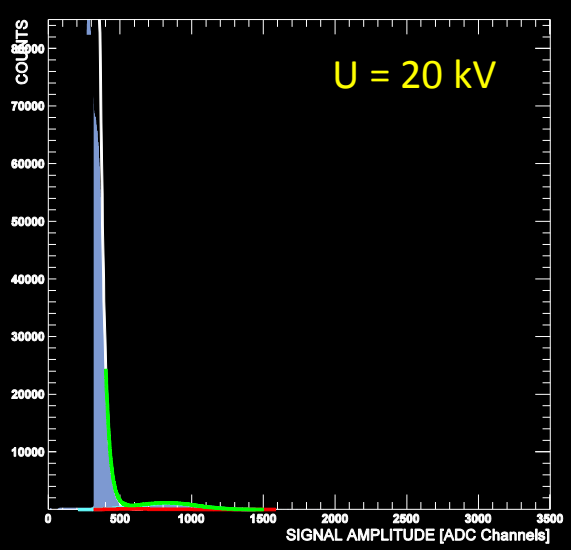

25 electrons
Back-Scattered
Cr-coating
Cr
Cr 40.00 nm
LYSO
LYSO CRYSTAL
0.0 r
172.0 r
344.1 r
516.1 r
688.1 r
-440.0 nm
-220.0 nm
0.0 nm
220.0 nm
440.0 nm
CASINO-2 Simulation

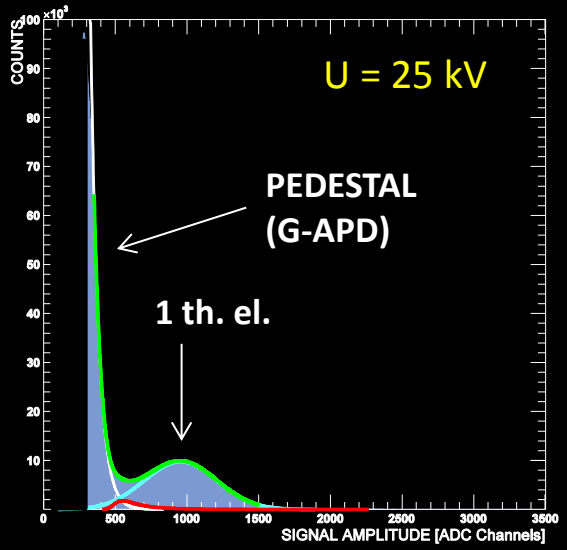
ELECTRON BACK-SCATTERING FROM THE LYSO WINDOWLET

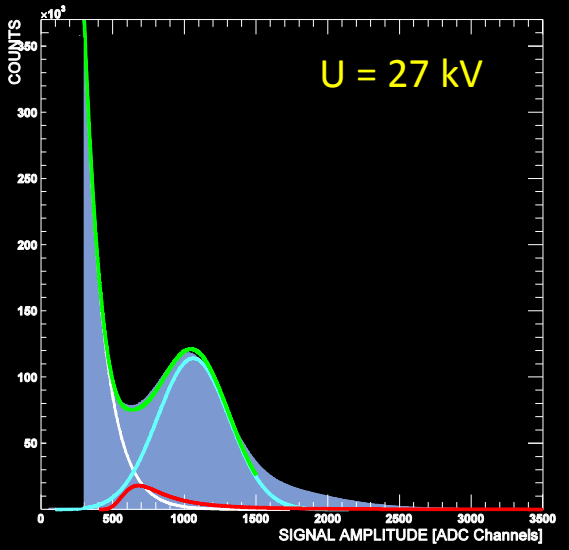


THERMIONIC ELECTRON EMISSION = f(U)

DARK COUNTS, WITHOUT A LIGHT SOURCE

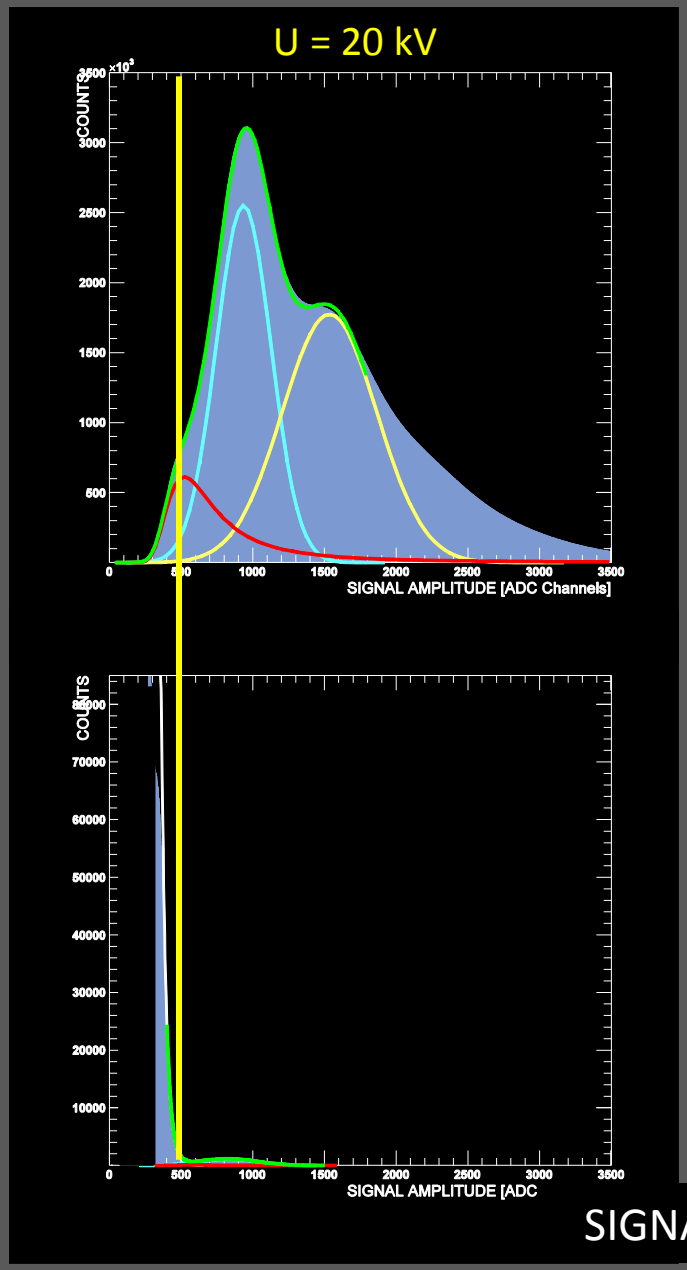


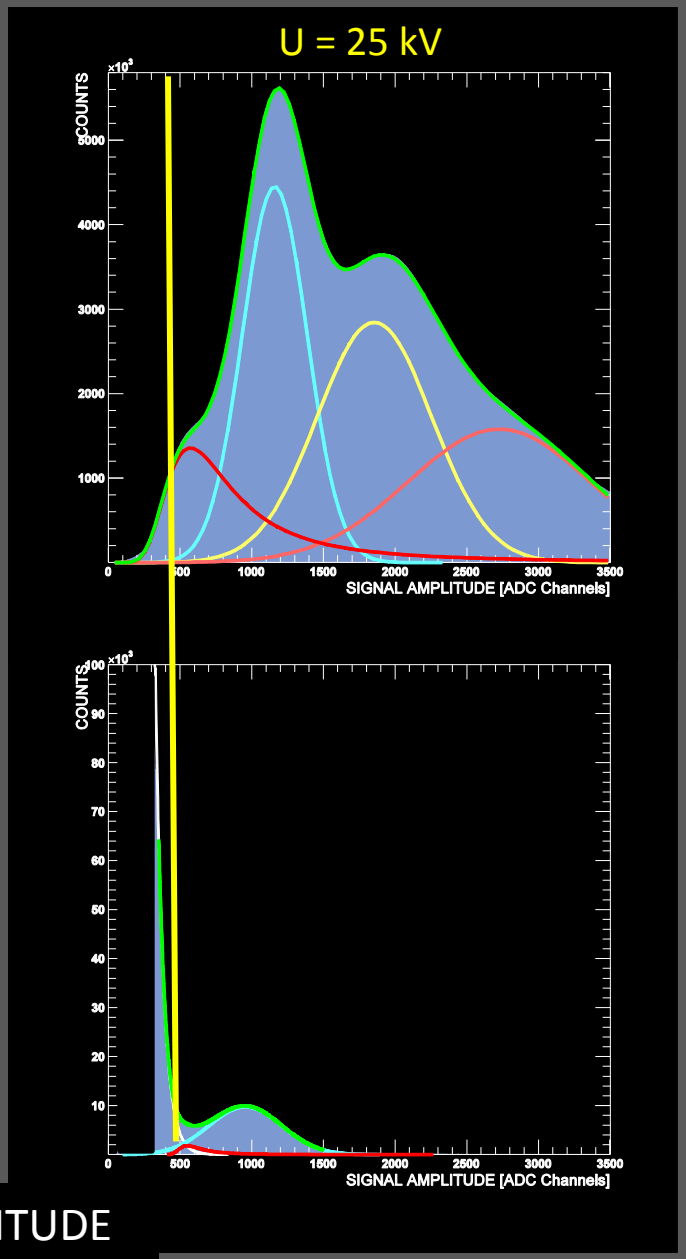




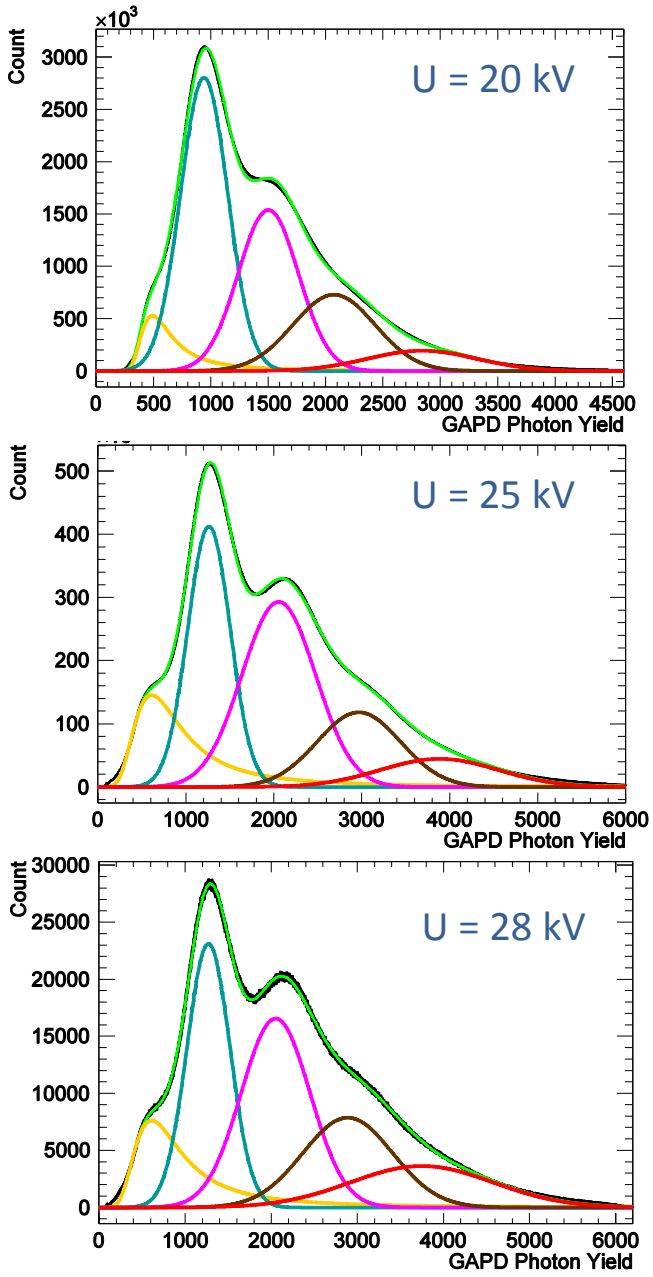
SIGNAL AMPLITUDE

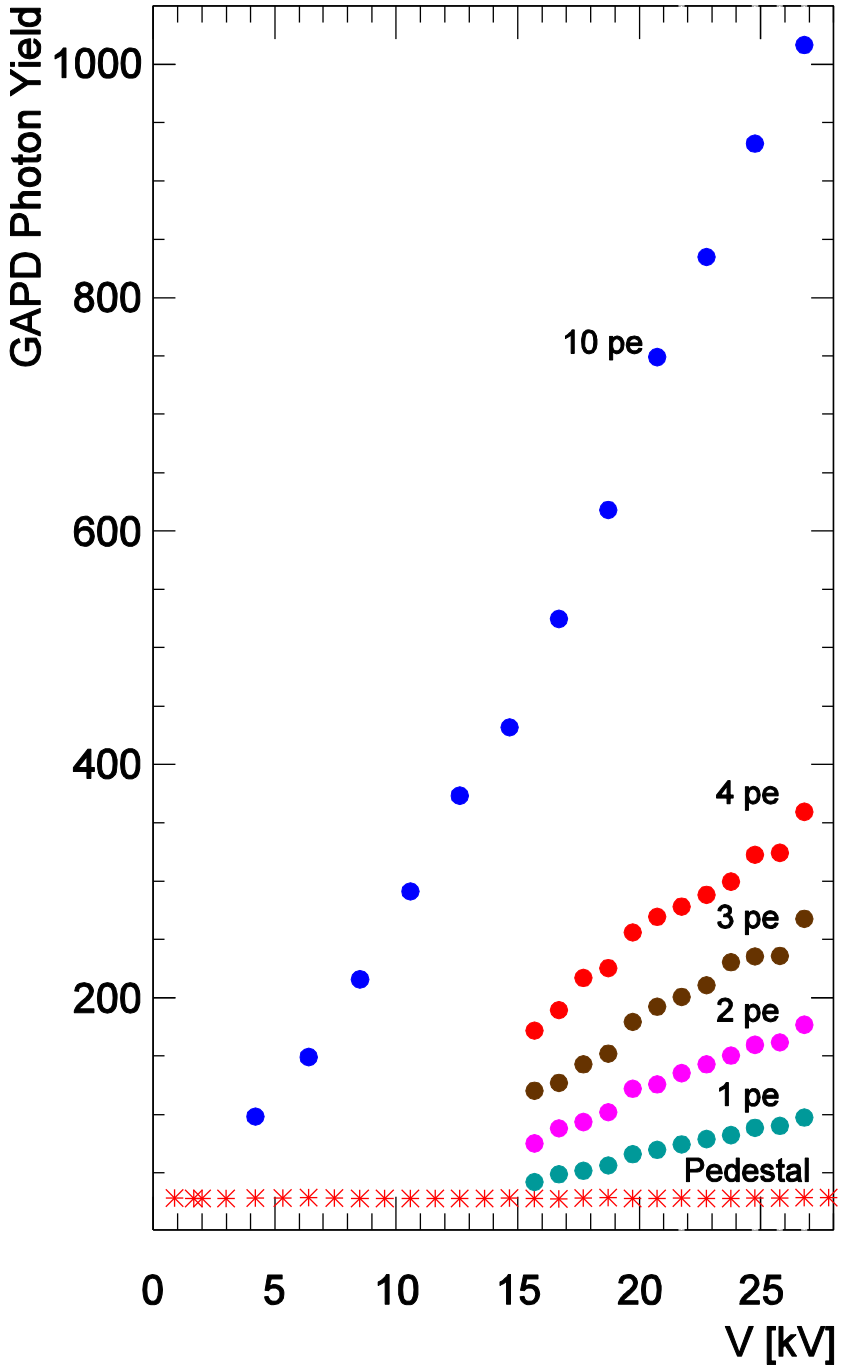
SIGNAL vs. PEDESTAL

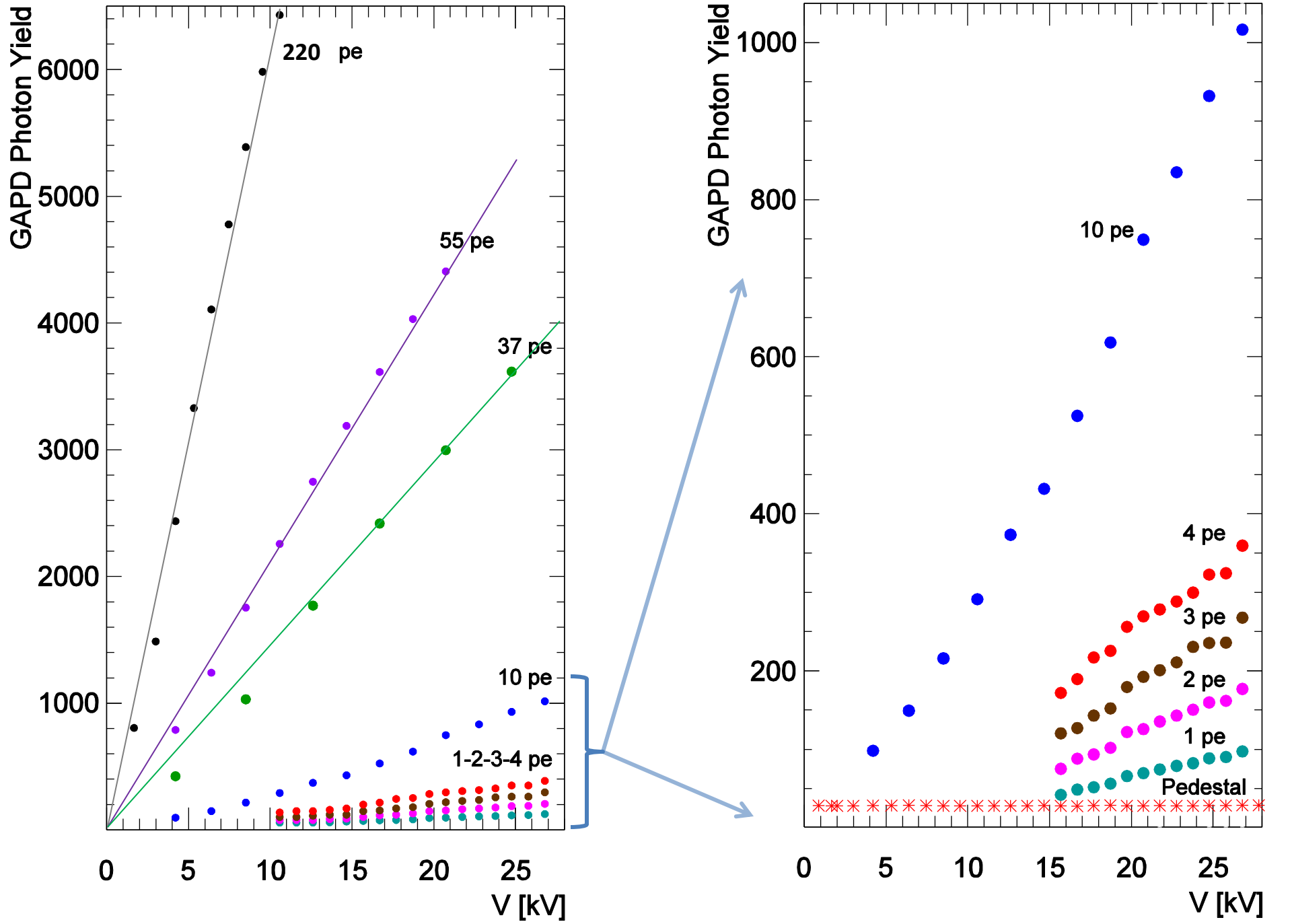




SIGNAL AMPLITUDE

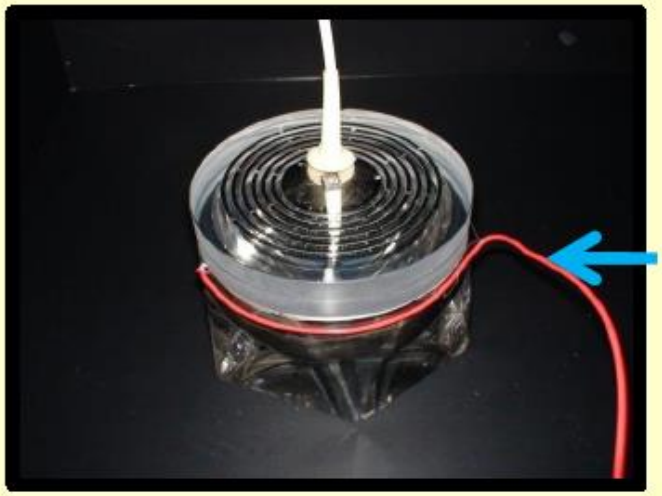

Count
×10³
U = 20 kV
GAPD Photon Yield
U = 25 kV
GAPD Photon Yield
U = 28 kV
GAPD Photon Yield


GAPD Photon Yield
10 pe
4 pe
3 pe
2 pe
1 pe
Pedestal
V [kV]


GAPD Photon Yield
6000
5000
4000
3000
2000
1000
220 pe
55 pe
37 pe
10 pe
1-2-3-4 pe
0
5
10
15
20
25
V [kV]
GAPD Photon Yield
1000
800
600
400
200
10 pe
4 pe
3 pe
2 pe
1 pe
Pedestal
0
5
10
15
20
25
V [kV]

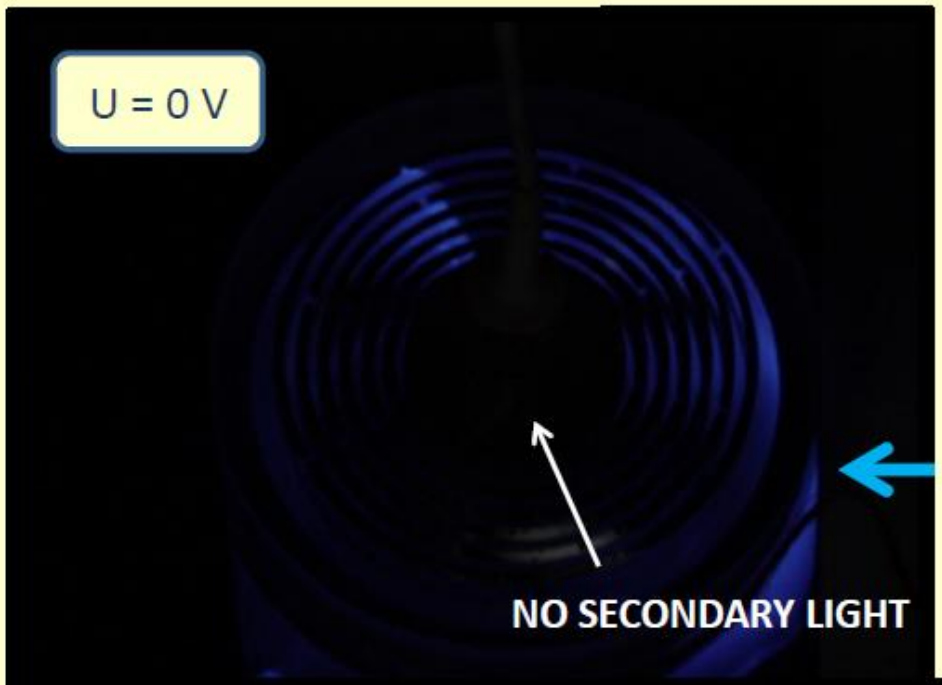
DYNAMIC RANGE AND OVEREXPOSURE SURVIVAL

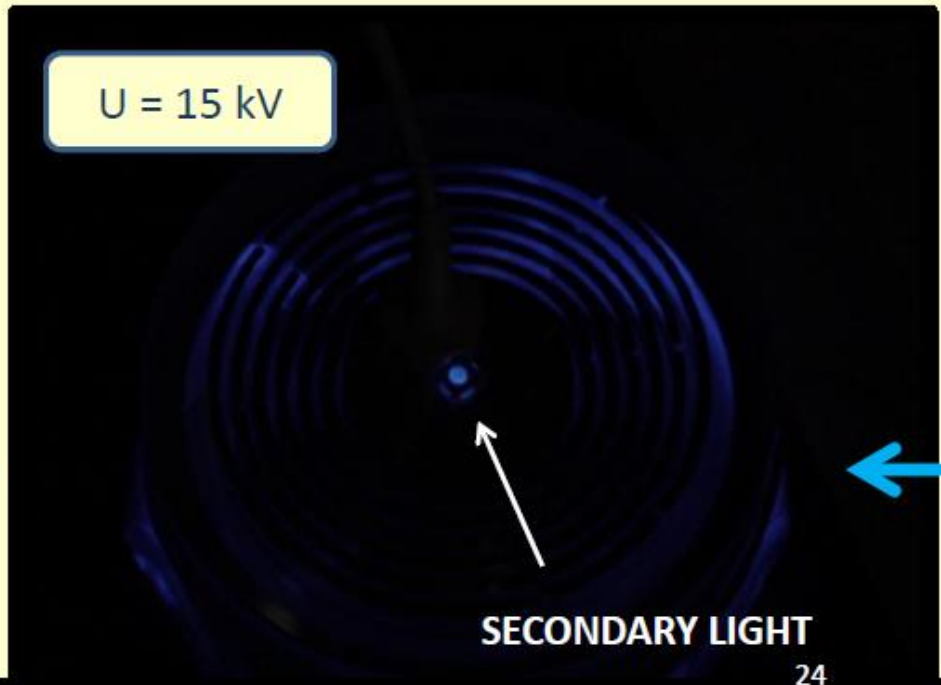
When ABALONE tube is exposed to a strong light source (in this case a near-UV lamp ←), the level of secondary light in the Windowlet is clearly visible by the naked eye (lower-right image, showing ABALONE when powered up). Unlike PMTs and HPDs, ABALONE can survive exposure to strong sources of light - even daylight.



For all practical purposes, the dynamic range of ABALONE sensors is 'infinite,' and limited exclusively by the granularity of the readout G-APD.

Patent No. 9,064,678





| ABALONE Prototype-12-05 |0-15keV | LYSO Crystal Windowlet type-1 | Light source: 405 nm DC | Visual Readout | Room temperature |

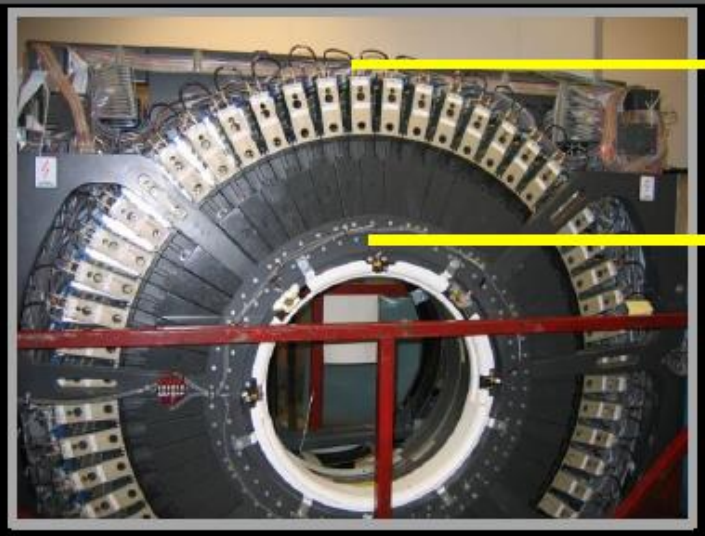
‘MODERN’ RING-PET vs. ABALONE-PET

BASED ON THE 80-YEAR-OLD PMT’s;
NOTE THE LARGE ‘THICKNESS’ OF THE RING -
A CONSEQUENCE OF PMT DRAWBACKS

→ A TRUE WHOLE-BODY PET SCANNER IS INCONCEIVABLE

A SELF-SUPPORTED DETECTOR SHELL, COMPRISED OF VERY THIN, LIGHTWEIGHT AND INEXPENSIVE FLAT-PANEL BOARDS

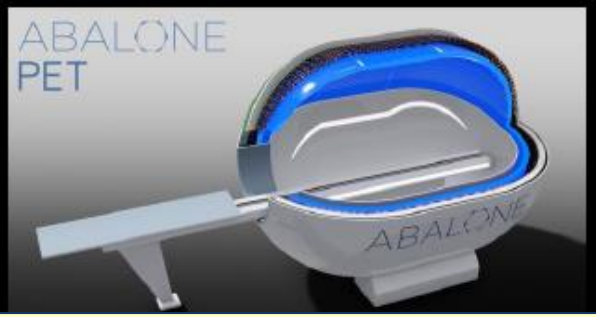
→ A TRUE WHOLE-BODY PET SCANNER FOLLOWS NATURALLY



~100 cm*

~5 cm*

(*) PHOTOSENSOR THICKNESSES – WITHOUT THE SCINTILLATOR



Patent No. 9,064,678 and patent pending PCT/US15/031188

SUMMARY

- WE HAVE SUCCESSFULLY DEMONSTRATED:
  - NOVEL MASS-PRODUCTION TECHNOLOGY FOR VACUUM PHOTOSENSORS, EQUIVALENT TO THE PRODUCTION OF CDs
  - ABALONE PHOTOSENSOR CONCEPT, DERIVED FROM THE ABALONE TECHNOLOGY Patent No. 9,064,678 and patent pending PCT/US15/031188
  - EXCEPTIONAL & UNIQUE ABALONE PROTOTYPE PERFORMANCE
- APPLICATIONS:
  - FUNDAMENTAL RESEARCH
  - MEDICAL IMAGING – ABALONE-PET
  - NUCLEAR SECURITY

CAN IT GET ANY SIMPLER, BETTER, CHEAPER ?

NEW DOORS ARE OPENING

THIS IS THE RIGHT TIME TO DISCUSS NEW IDEAS

WELCOME TO OUR LABS FOR HAND-ON EXPERIENCE