

THE ABALONE™ PHOTODIODE TECHNOLOGY

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& Partners/Customers:
*From the IceCube Experiment,
Supported by our ongoing NSF (SBIR) project
also DARWIN Project, ...*

THIS
TALK

COMING
TALKS

Manufacturers of glass, quartz, scintillator, & industrial equipment

WHAT IS THE *ABALONE*[™] PHOTODSENSOR TECHNOLOGY?

= SCALABLE NEW TECHNOLOGY FOR
LARGE-VOLUME-PRODUCTION OF
LARGE-AREA PHOTODSENSORS

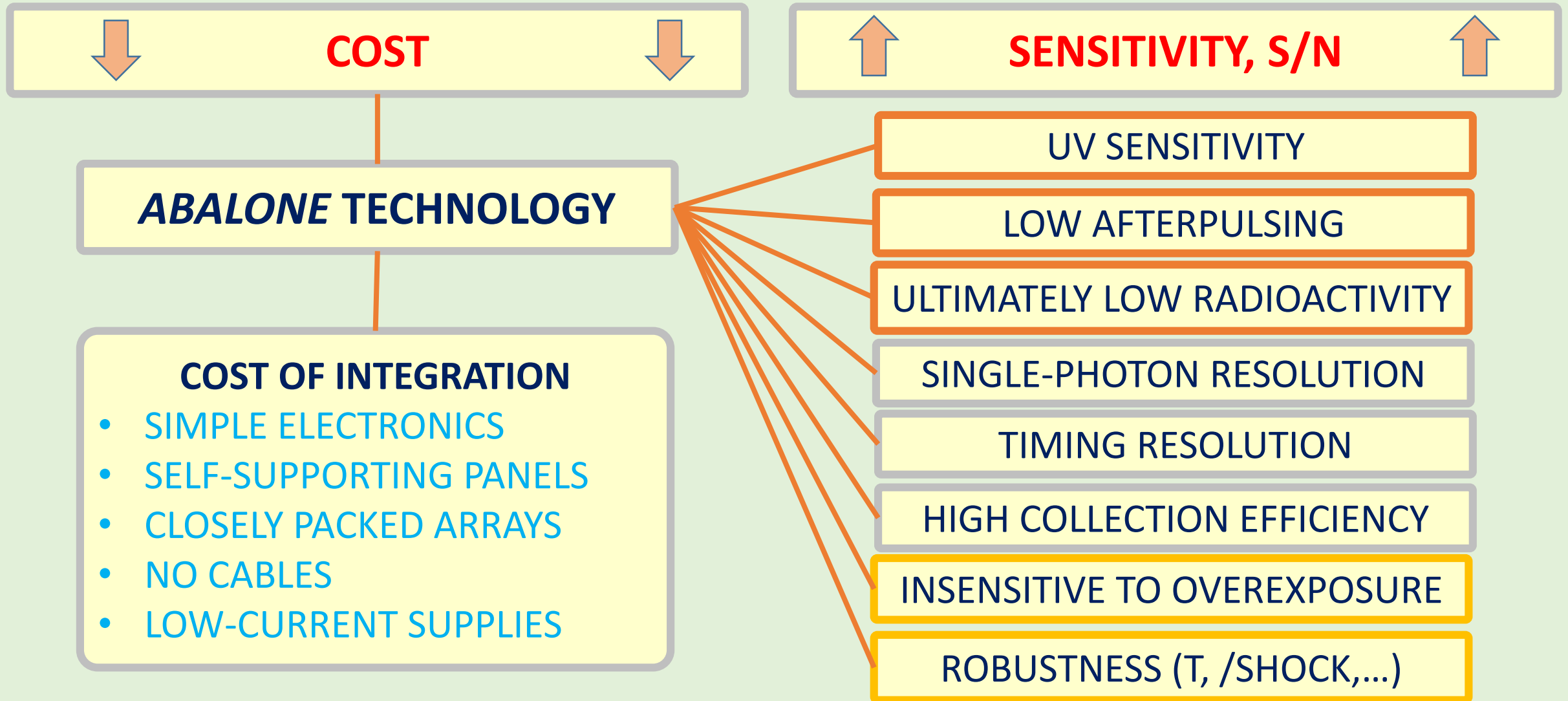
BASED EXCLUSIVELY

ON PROVEN MODERN MASS-PRODUCTION METHODS

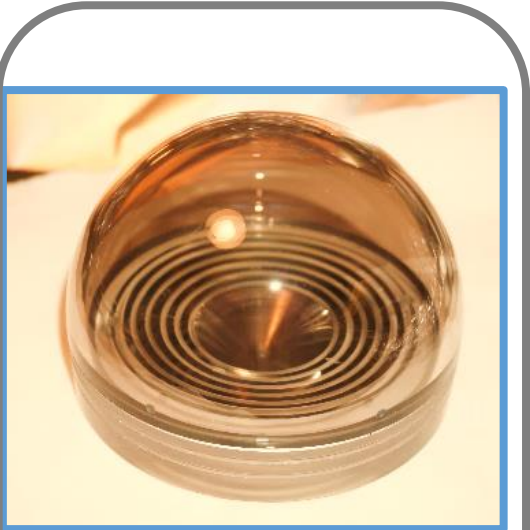
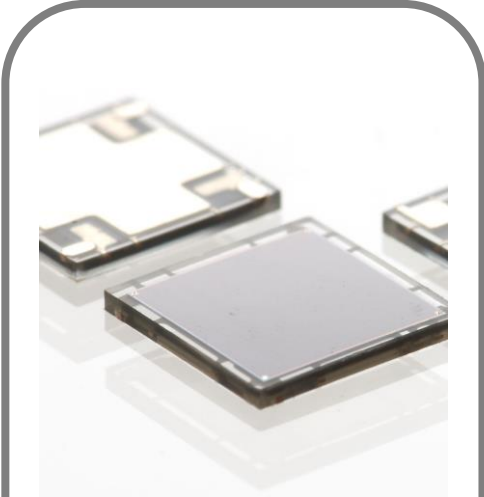
(RAPID LOW-TEMP. CLEANING & THIN-FILM DEPOSITION)

- PATENTED (U.S. Patent 9,064,678, 2015; WO 2015/176000 A1, PCT/US2015/031188, 2014, US-2017-0123084-A1.)
- **PERFORMANCE-TESTED – CONTINUOUSLY OVER 4 YEARS**
- COMMERCIALIZED (SBIR etc.)

THE NEEDS OF THE ASTRO-PARTICLE PHYSICS COMMUNITY (RESULTS OF THE “MARKET STUDY” DONE WITHIN THE NSF-SBIR PROGRAM)



ABALONE TECHNOLOGY – BYPASSING THE ‘OLD-TECHNOLOGY BARRIER’



G-APDs (SiPM)
> \$ 1-10 / mm²
> \$ 1-10 M / m²

PMTs
80-YEAR OLD
> \$ 0.1 /mm²
> \$ 100,000 / m²

PLASMA TVs
< \$ 0.0005 /mm²
< \$ 500 / m²

ABALONE
TECHNOLOGY
MUCH SIMPLER THAN
PLASMA TV

THE OLD-TECHNOLOGY BARRIER

ASTRONOMIC PRICE
a

EXTREMELY EXPENSIVE
b

APPROPRIATELY PRICED
c

APPROPRIATELY PRICED
d

PMT

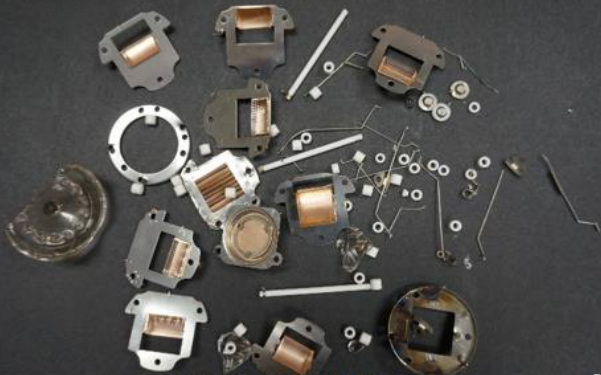


GLASS-BLOWN HOUSING

a

THE OLD-TECHNOLOGY BARRIER

?



>180 COMPONENTS

b

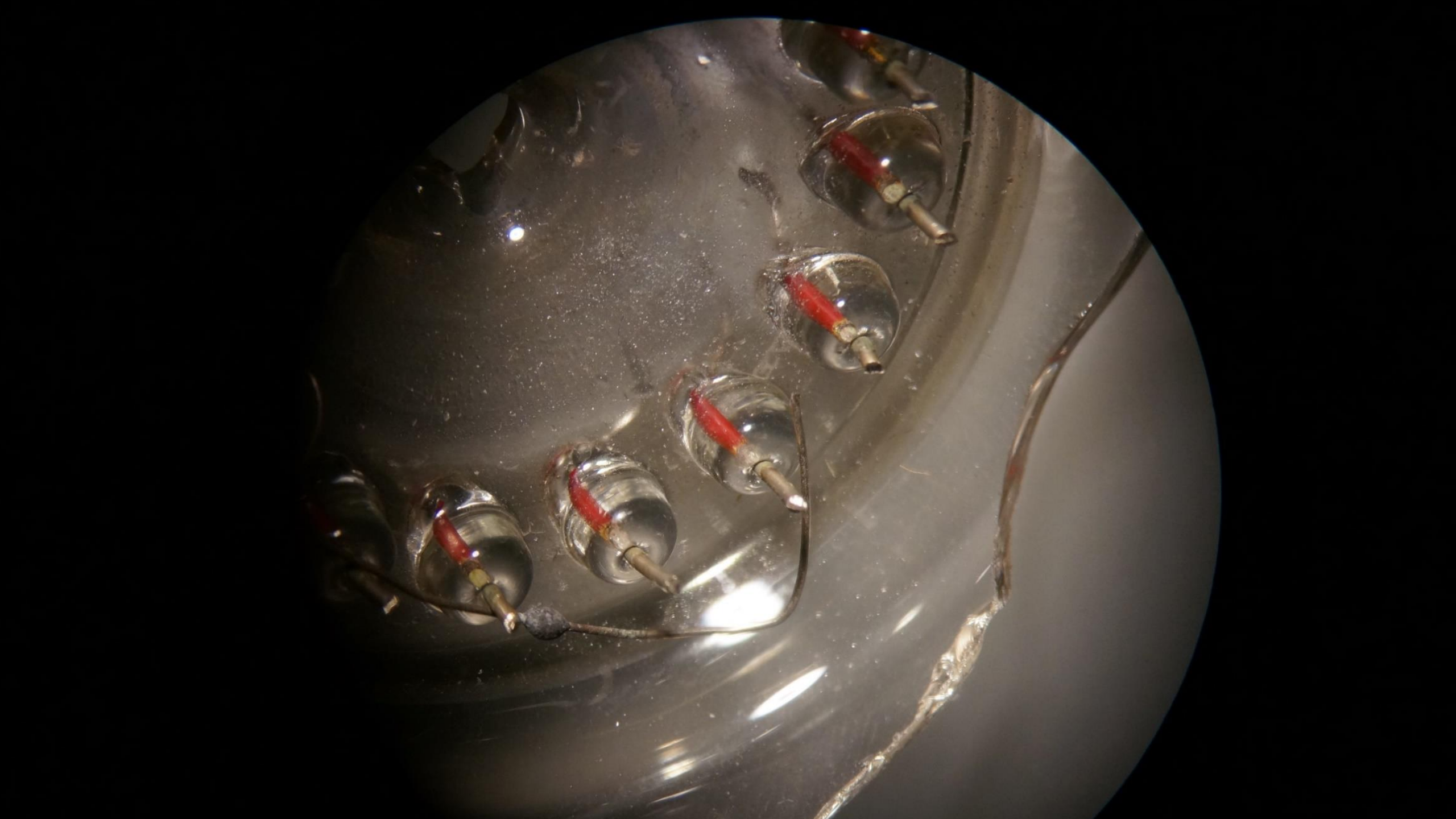
FINE GRIDS – EXPENSIVE AND FRAGILE



SPOT-WELDS

>400 SPOT-WELDS

c

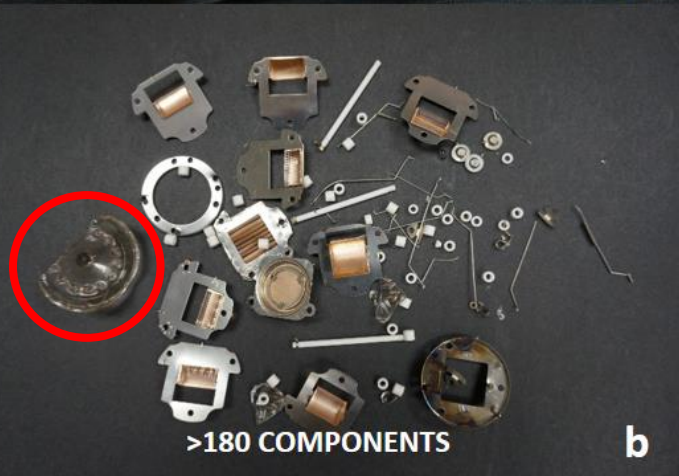


PMT



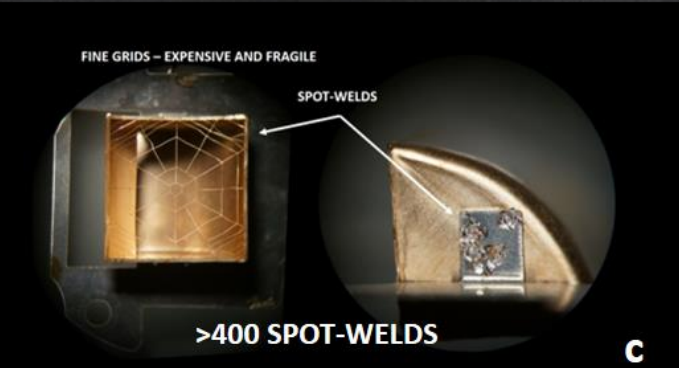
GLASS-BLOWN HOUSING

a



>180 COMPONENTS

b



FINE GRIDS - EXPENSIVE AND FRAGILE

SPOT-WELDS

>400 SPOT-WELDS

c

**THE OLD-TECHNOLOGY BARRIER
DUE TO THE INTRINSIC
COMBINATION OF MATERIALS**



BATCH PRODUCTION



**PRECLUDES MODERN
CONTINUOUS
PRODUCTION LINE**



The 80-YEAR
OLD PMT
TECHNOLOGY

180
HAND-MADE
COMPONENTS

400
HAND-MADE
SPOT-WELDS

BATCH
PROCESS

VERY SLOW AND
EXPENSIVE



PMT COMPONENTS



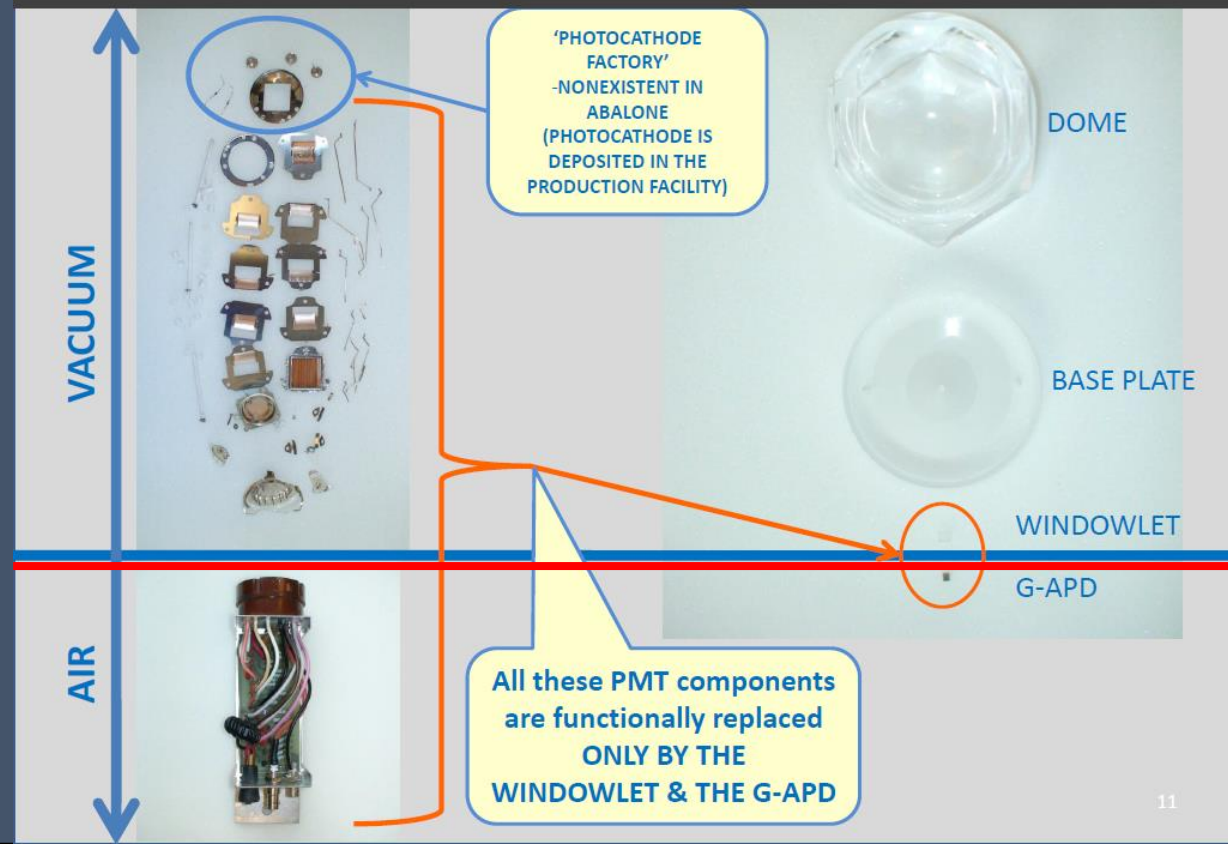
ABALONE COMPONENTS

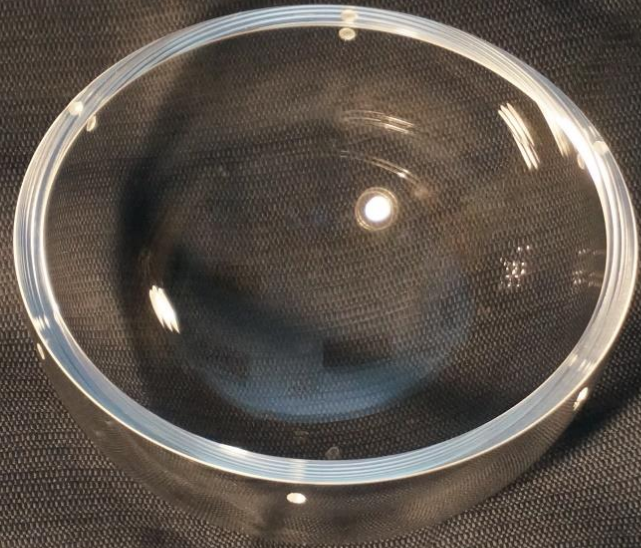
THE ABALONE
TECHNOLOGY

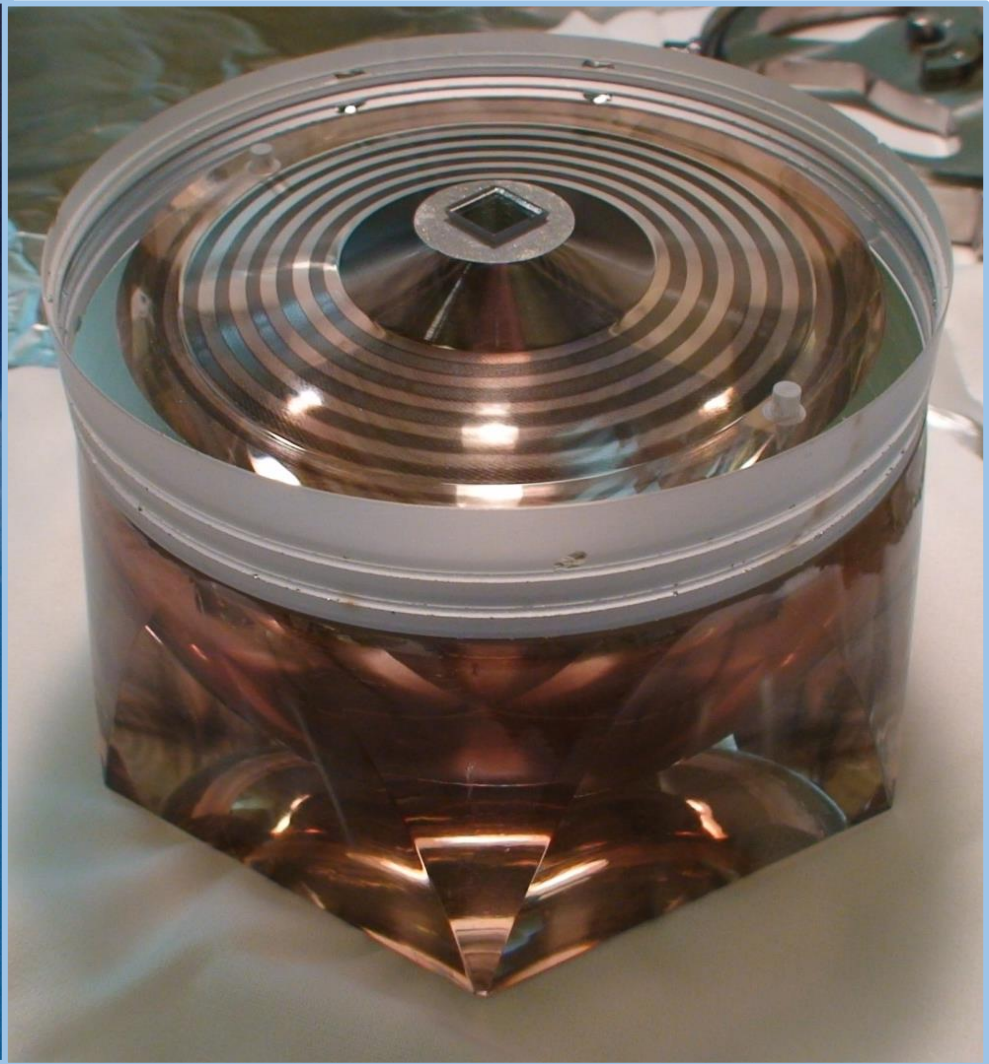
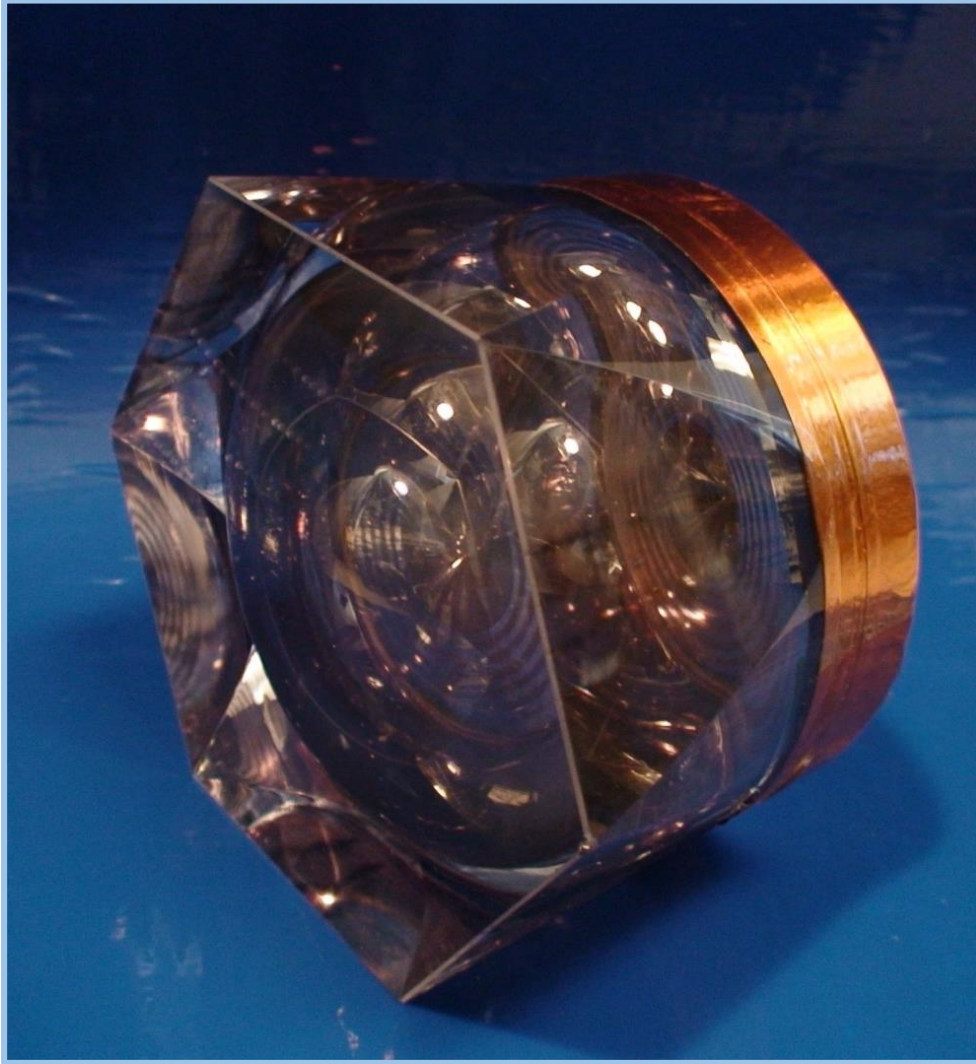
3
COMPONENTS
GLASS ONLY

STANDARD
THIN-FILM
DEPOSITION
PROCESS

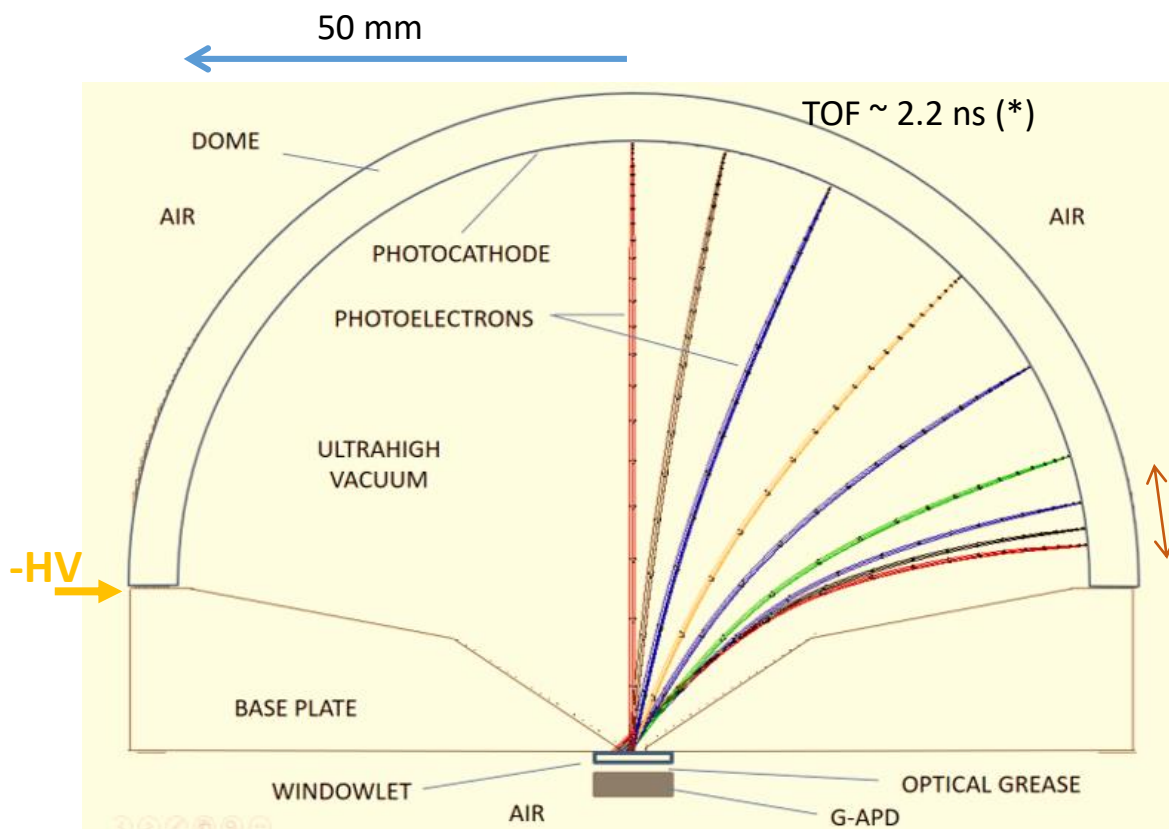
BYPASSING THE
OLD-
TECHNOLOGY
BARRIER







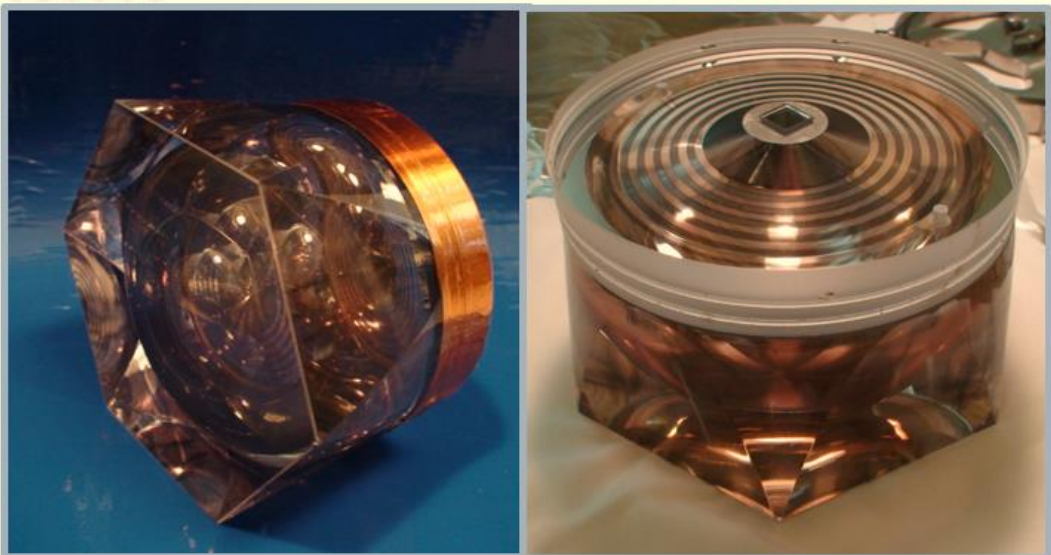
NOW:
MOLDED
FUSED
SILICA



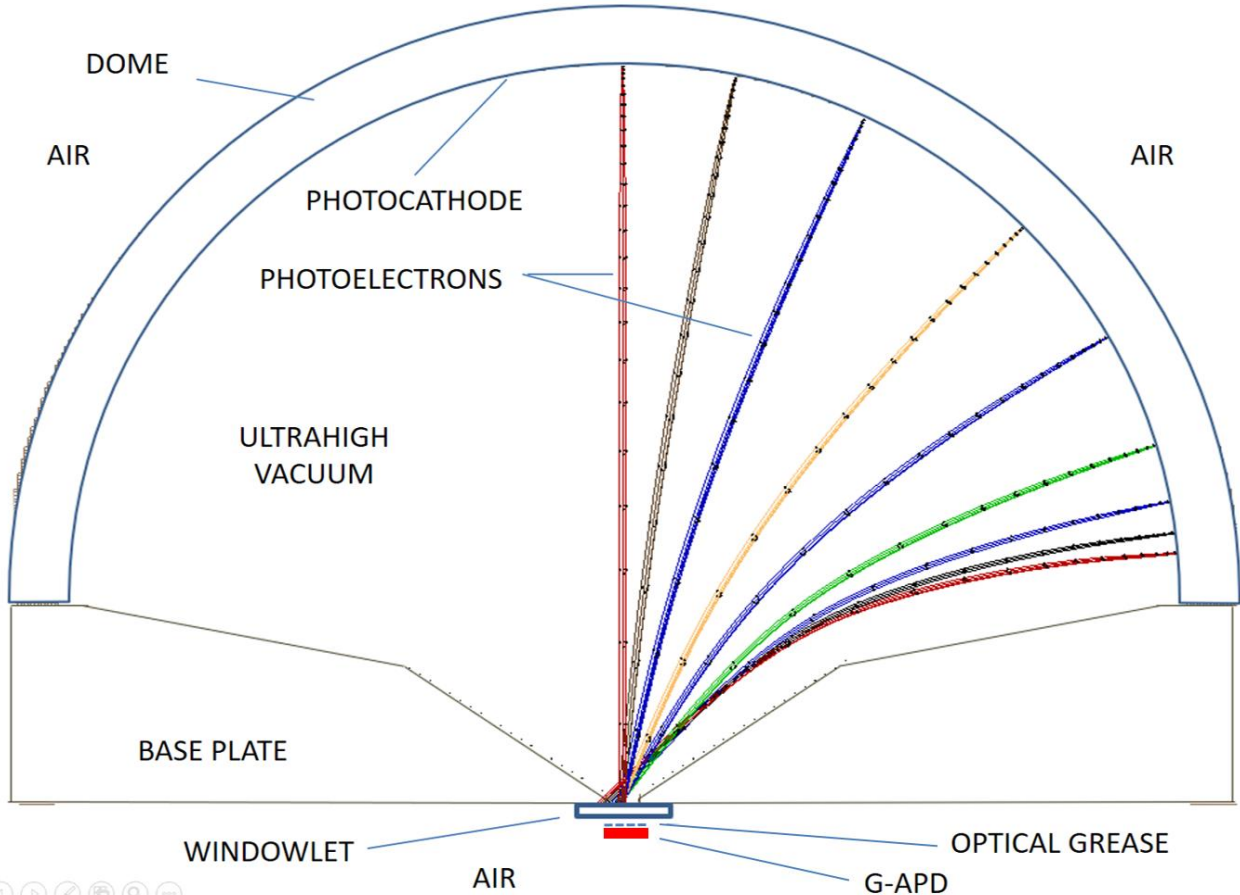
ONE 25 keV PHOTOELECTRON
GENERATES
~ 23 photons/keV IN LYSO

→ 580 photons
→ G-APD DETECTS ~ 60 ph

(*) for 25keV; TOF ~ HV^{-1/2}



THE IMPORTANCE OF **NOT** BEING IN THE VACUUM



UNLIKE IN
HPDs
(!)

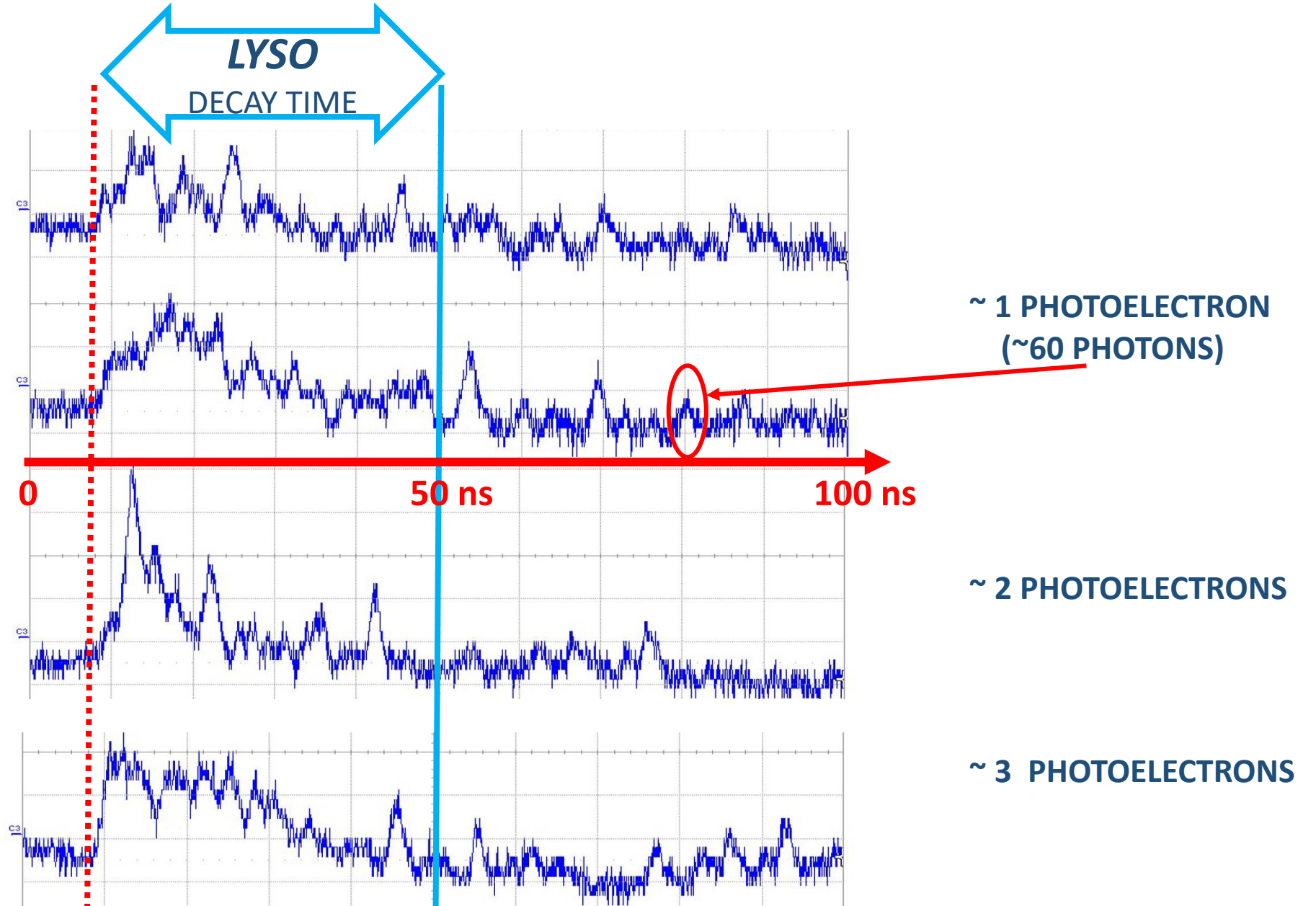
THE FOCUSING FIELD
IS CO-FORMED
OUTSIDE THE VACUUM

THE G-APD IS PLACED
OUTSIDE THE VACUUM

WAVEFORM EXAMPLES

READOUT BY A 5 GHz SCOPE

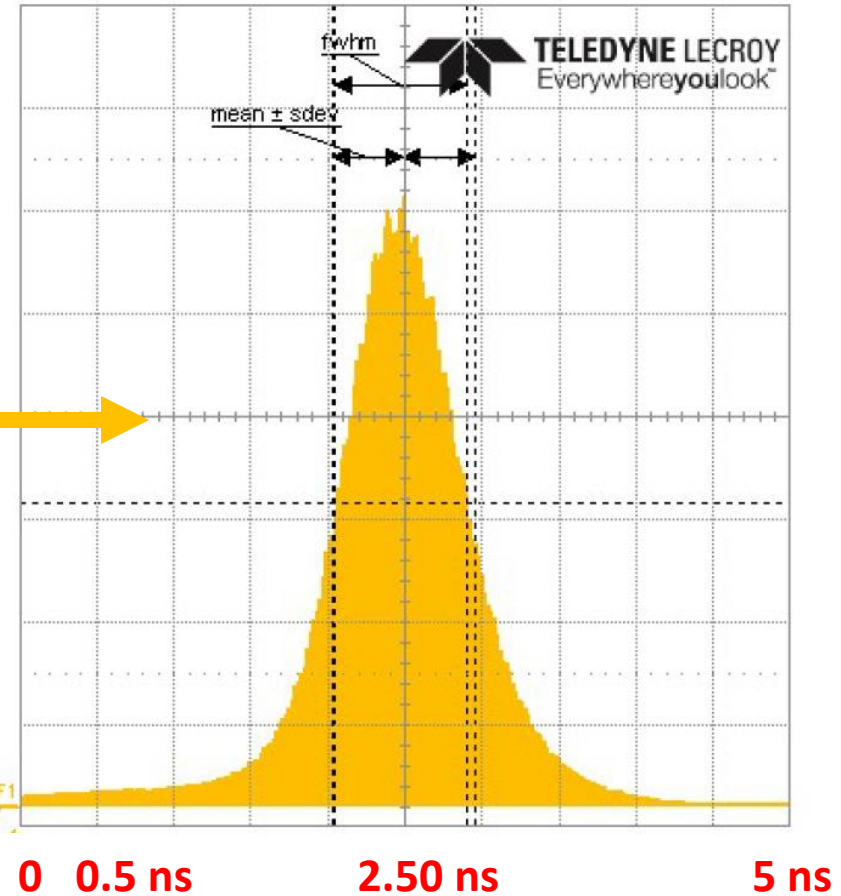
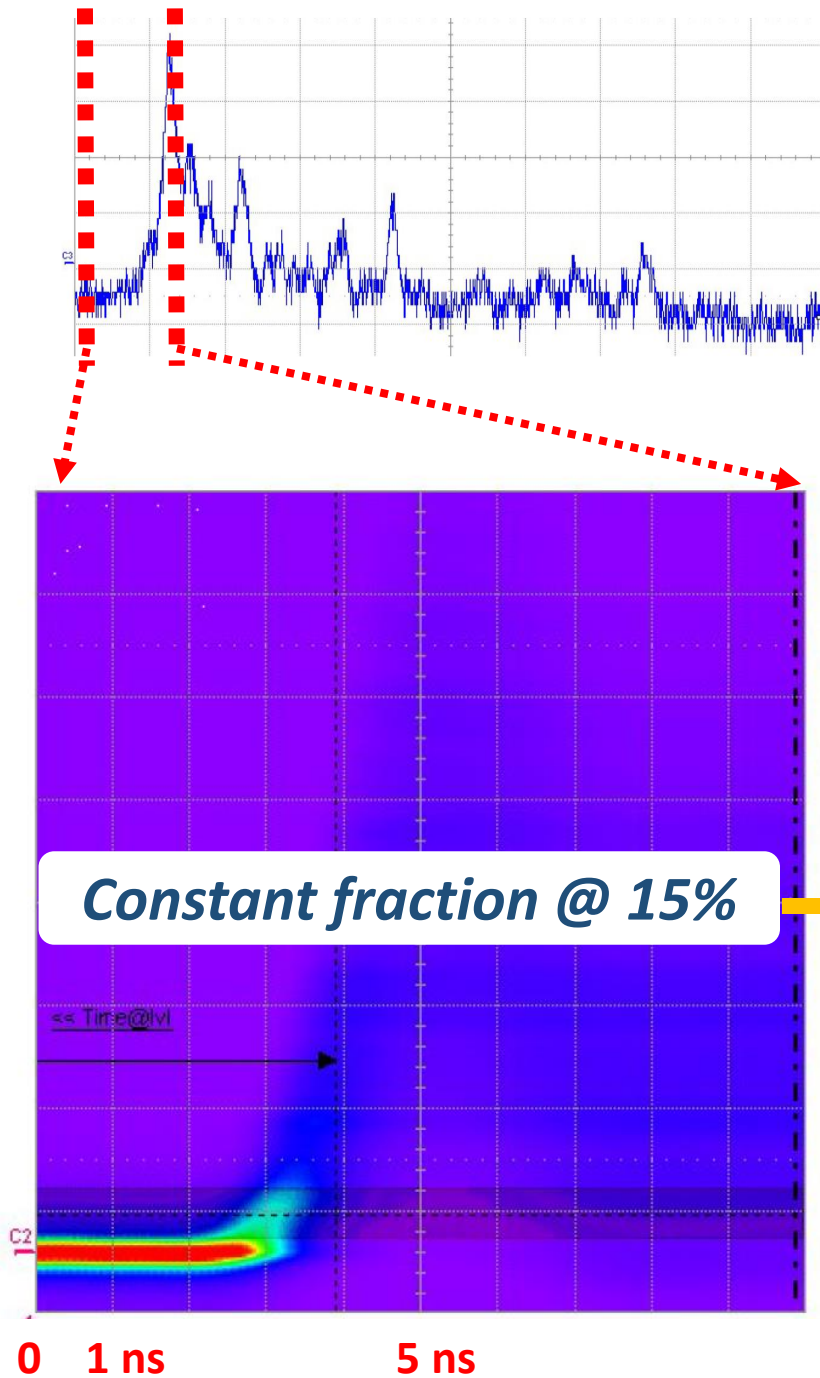
- NO FILTERING
- NO AMPLIFICATION
- U = 25 kV
- 3X3 SensL J-type G-APD @ -30.5 V
- FAST G-APD SIGNAL



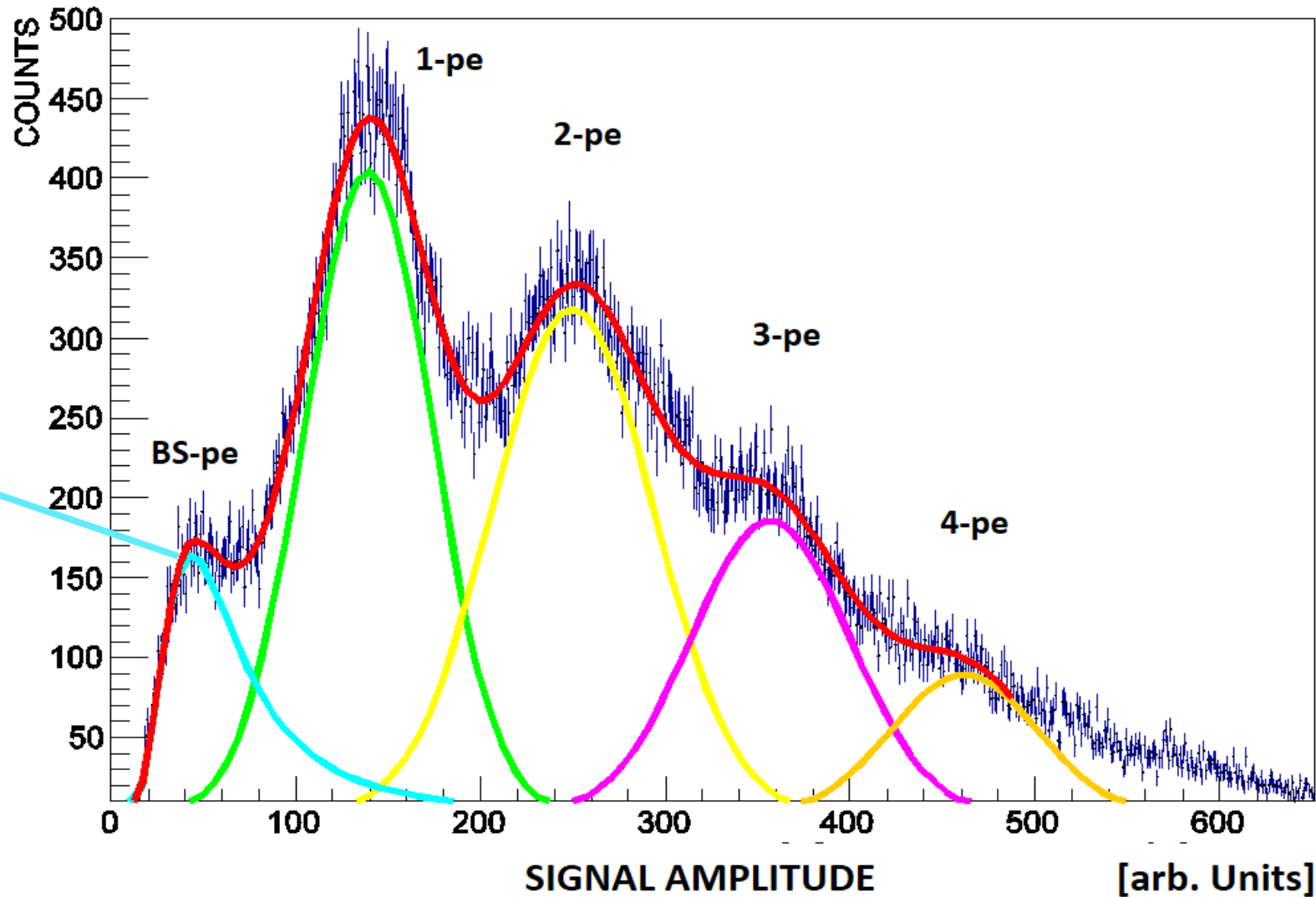
TIMING RESOLUTION

fw hm = 856 ps

- Non-ideal (spherical) Dome shape, and
- An estimated *500 ps* wide LED-pulsers



SINGLE-PHOTON RESOLUTION



NON-RETURNING
BACK-SCATTERED
PHOTOELECTRONS

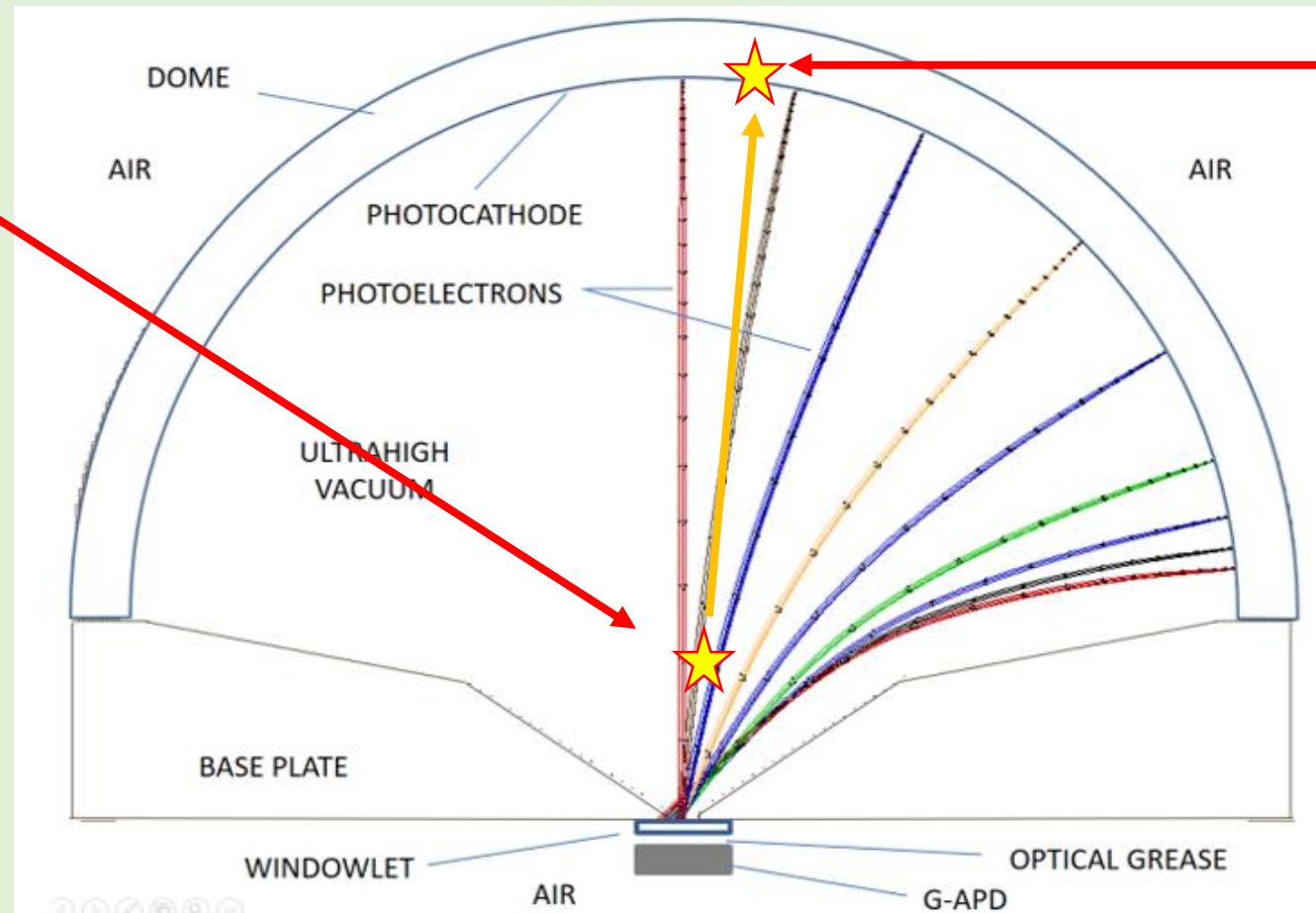
THE INTEGRATED SLOW SensL SIGNAL

VACUUM INTEGRITY, AFTERPULSING AND Hans Bethe's $(-dE/dx)$

PHOTOELECTRONS: $-dE/dx \sim 1/\beta^2 \sim m/E_K$

IONS: LEFT SIDE OF THE $(-dE/dx)$ PEAK

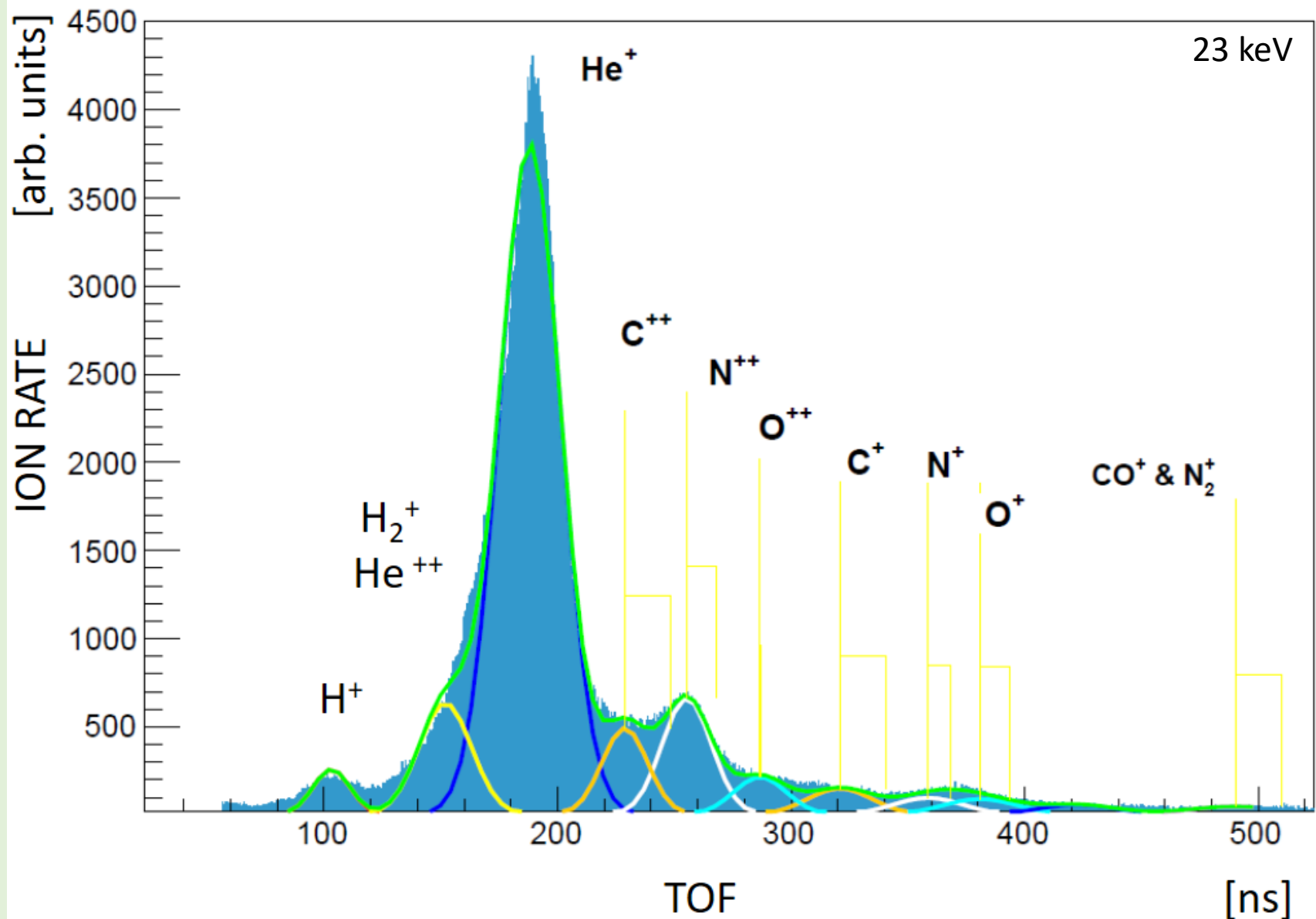
**~100 X LESS
IONIZATION THAN
IN A PMT**
($E \sim 20$ keV
vs. 200 V)



**ION IMPLANTATION
IN GLASS**

- LESS IONIZATION AND DAMAGE TO THE PHOTOCATHODE
- WEAKER AFTERPULSES
- ACTIVE VACUUM PUMPING

TIME-OF-FLIGHT MASS SPECTROSCOPY ANALYSIS OF THE RESIDUAL GAS

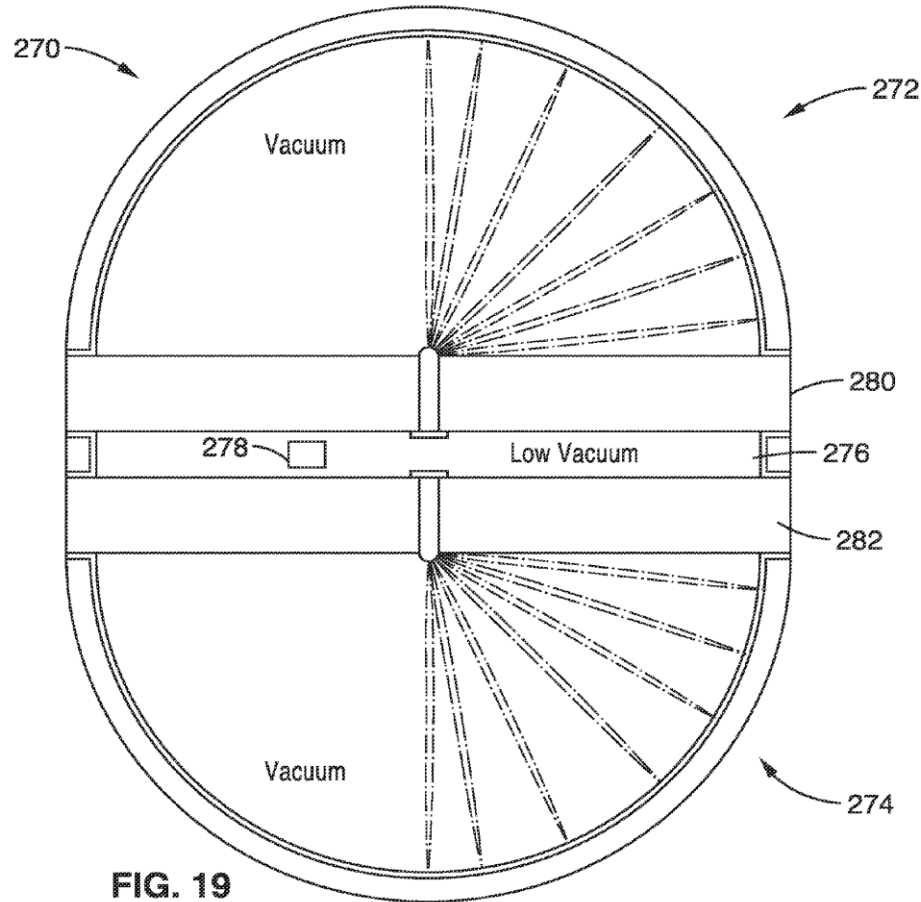


4 YEARS OF CONTINUOUS PROTOTYPE TESTING

- He – DOMINANT BECAUSE IT PENETRATES GLASS
- OTHER IONS HAVE BEEN PERMANENTLY PUMPED
 - CHEMISORPTION
 - ION IMPLANTATION
- **FACTOR 100 LESS AFTERPULSING THAN IN PMTs, ALTHOUGH THE SAME He PRESSURE ! (Hans Bethe)**

THE CONCEPT OF 'TANDEM-ABALONE' FOR IceCube II AND OTHER WATER-CHERENKOV DETECTORS (CURRENT NSF-SBIR)

U.S. Patent Jun. 23, 2015 Sheet 16 of 17 US 9,064,678



CONCLUSION

PROPERLY ADDRESSING THE NEEDS OF THE
WIDE ASTRO-PARTICLE PHYSICS COMMUNITY

↓
COST
↓

↑
SENSITIVITY, S/N
↑

ABALONE TECHNOLOGY

COST OF INTEGRATION

- SIMPLE ELECTRONICS
- SELF-SUPPORTING PANELS
- CLOSELY PACKED ARRAYS
- NO CABLES
- LOW-CURRENT SUPPLIES

UV SENSITIVITY

LOW AFTERPULSING

ULTIMATELY LOW RADIOACTIVITY

SINGLE-PHOTON RESOLUTION

TIMING RESOLUTION

HIGH COLLECTION EFFICIENCY

INSENSITIVE TO OVEREXPOSURE

ROBUSTNESS (T, /SHOCK,...)