Advanced Photodetection Concepts

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Work supported by National Nuclear Security Administration (NNSA), Office of Nonproliferation Research and Engineering, DOE, and

two Advanced Detector Awards, Office of Science, DOE

OUTLINE

- MOTIVATION
- OBJECTIVES
- SOLUTIONS:
  - Reflection-mode PC flat panel (ReFerence)
  - Transmission-mode hemispherical PC flat panel (ArcaLux)
  - NEW: Transmission-mode hemispherical PC pixels for a flat panel

COMPREHENSIVE REVIEW:

Daniel Ferenc and Eckart Lorenz, "Novel photosensors for neutrino detectors and telescopes," Earth Moon Planet (2007) 100:241–257

http://www.physics.ucdavis.edu/ferenc/Springer/draft.pdf

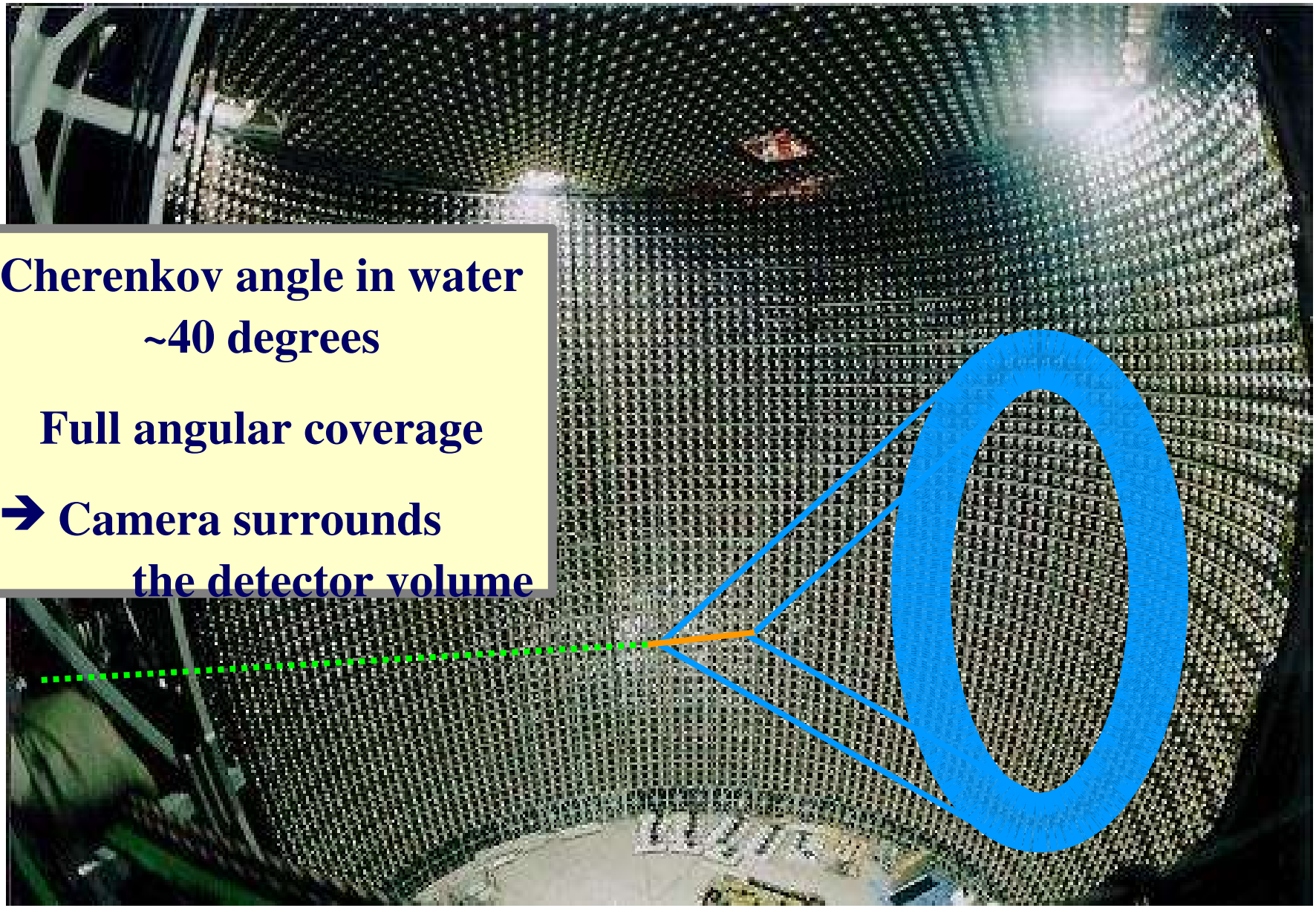
3 patents, serach Google patent site for D.F.

Very rare and/or weak radiation phenomena

- Nuclear Nonproliferation and Homeland Security
- Widely Accessible Medical Diagnostics (PET, SPECT, gamma)
- 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

The Unbeatable Reality of Mr. Liouville



Cherenkov angle in water
~40 degrees

Full angular coverage

➔ **Camera surrounds the detector volume**

Irreducibly Large Illuminated Area

strong internal signal concentration

Vacuum

(photon → photoelectron → 'no more Liouville')

WHY

(1) THE PMT COST IS HIGH

(2) THE QUANTITY IS LIMITED

?

50% - DYNODE COLUMN

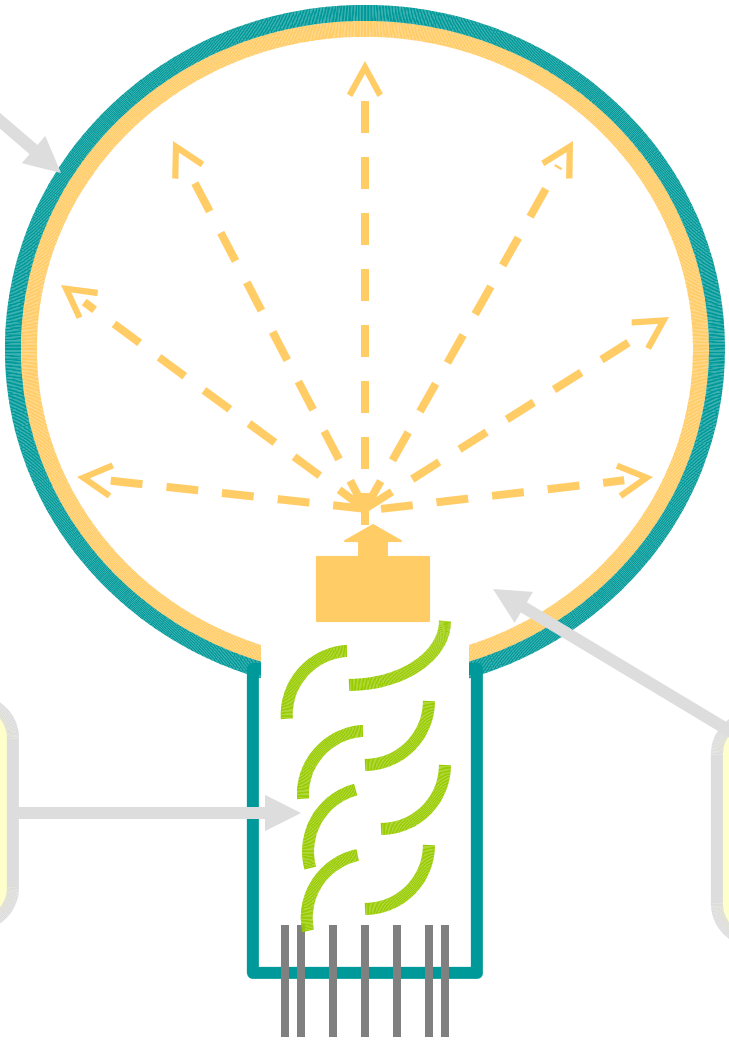
50% - GLASS BULB

→ **HAND-MADE COMPONENTS**

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

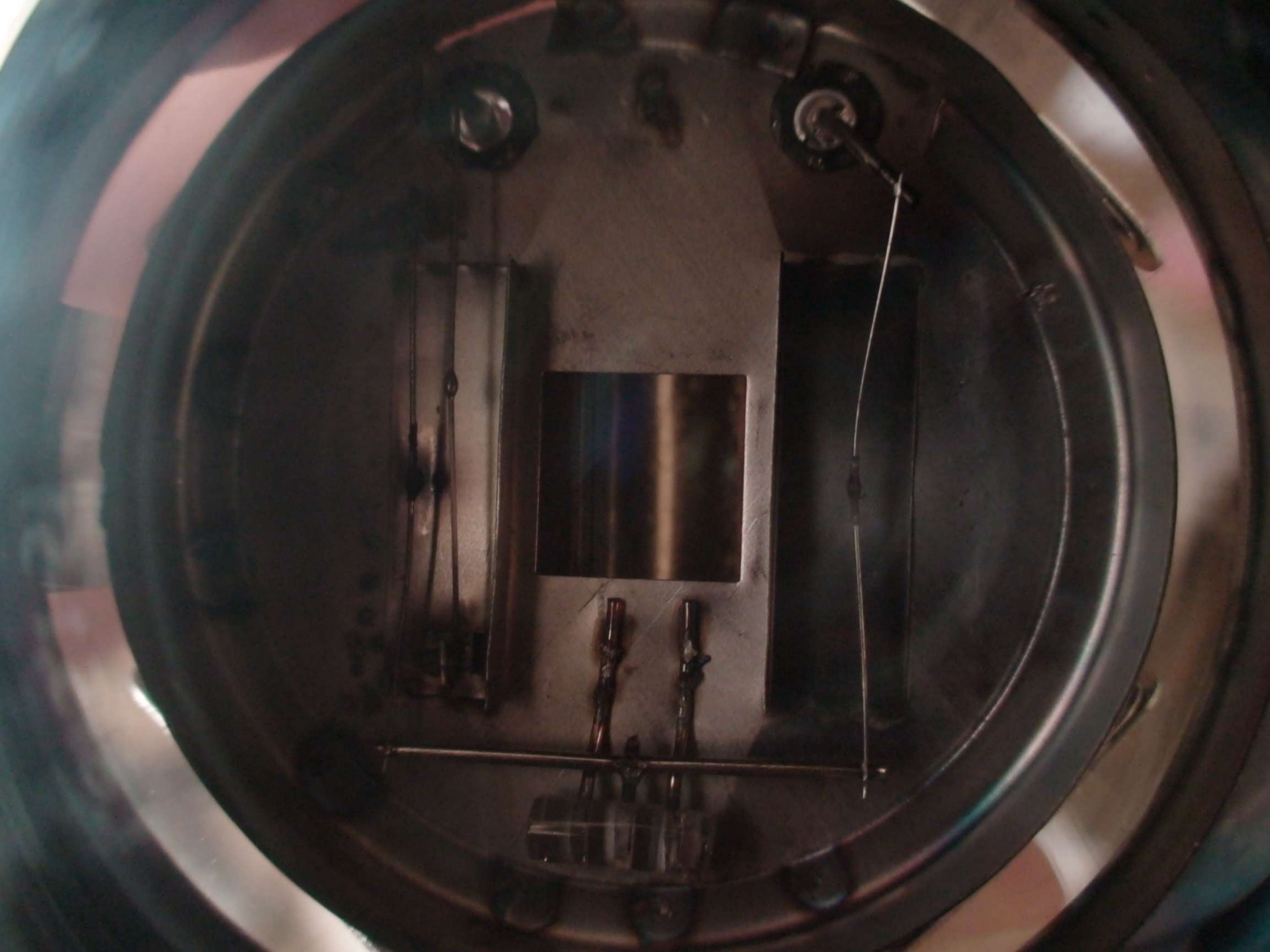
Every PMT – ‘its own factory’

handmade



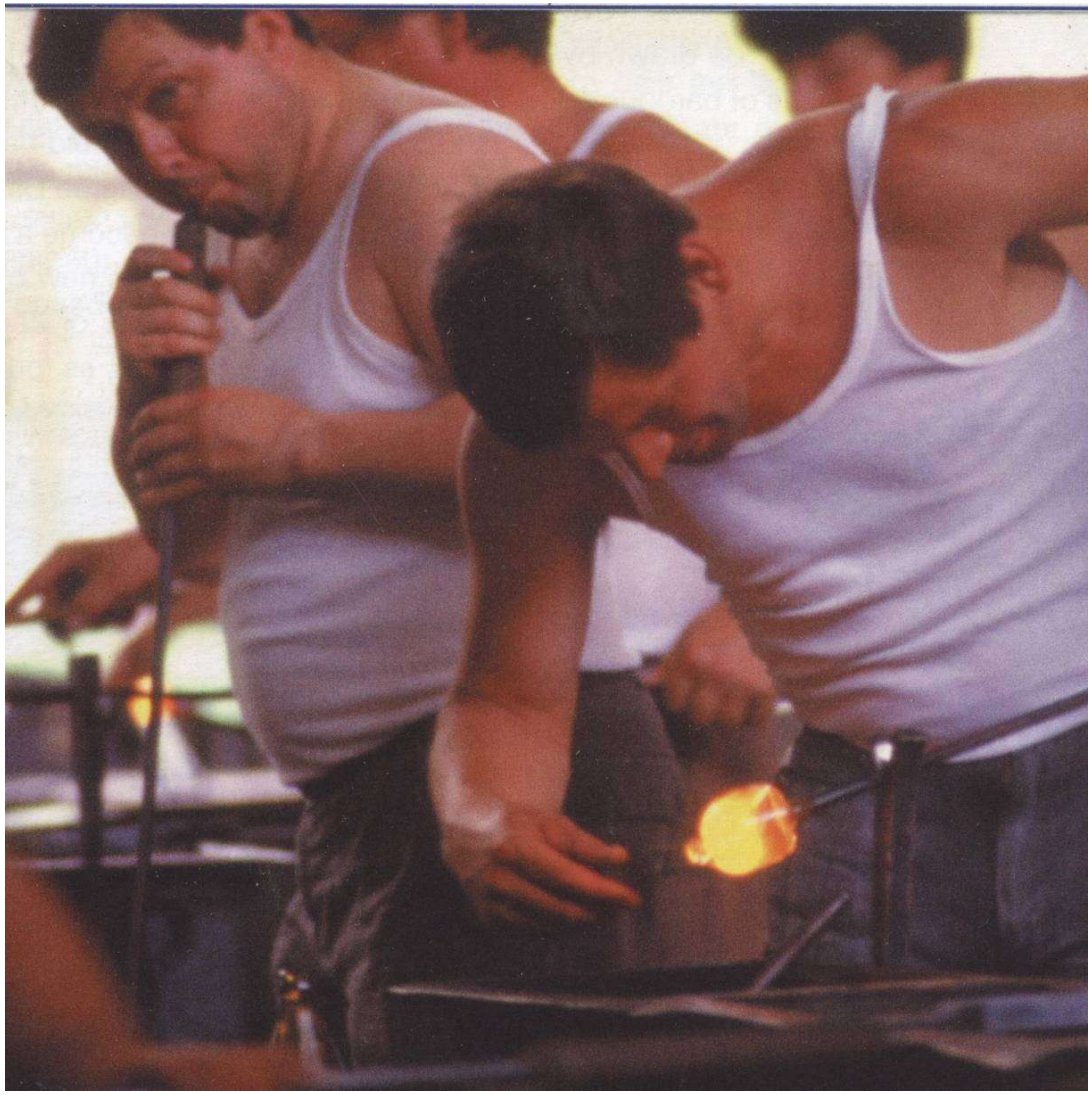
handmade

Cs, K, Na, Sb



A GLASS TUBE FACTORY

~100 x



PMT DYNODE FACTORY

Development of Other Vacuum Devices

~1960

~2000

Production Cost '07 < $500/m²

OUR GOAL

to introduce a new Technology for

industrial mass production

of large quantities

of large photosensors

based on modified existing technologies

+ FOCUS on some 'REAL' (non-physics) MARKETS

+ WORK OUT SCALLABLE MASS-PRODUCTION SCHEMES and IN-HOUSE PRODUCTION

ENCLOSURE:

FLAT-PANEL TV

3 existing

mass-production technologies

PHOTON→ELECTRON CONVERSION:

CLASSICAL PHOTOCATHODE

ELECTRON DETECTION:

SEMICONDUCTOR

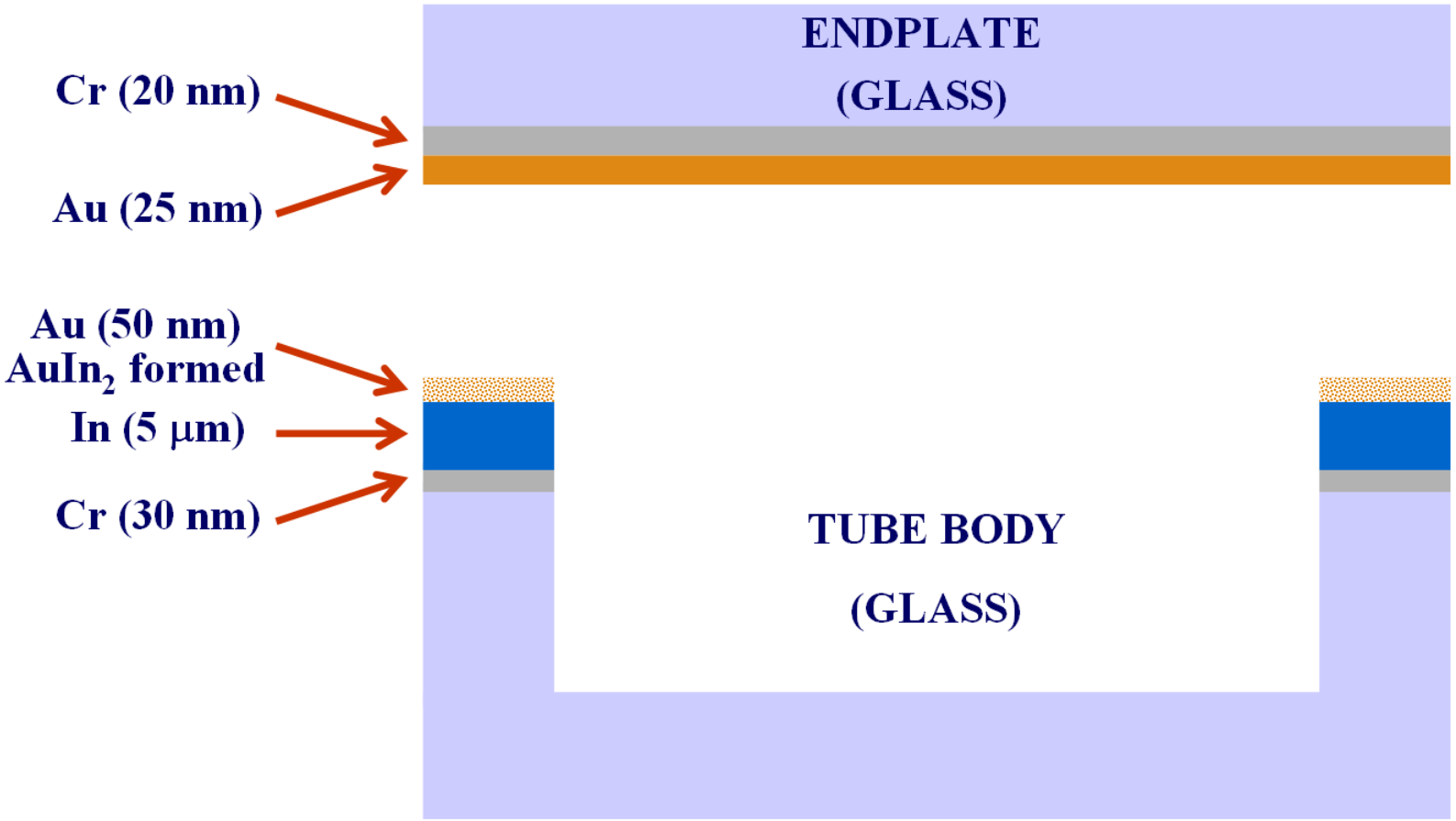
Scintillator + Geiger-MODE AVALANCHE DIODE

'Light Amplifier'

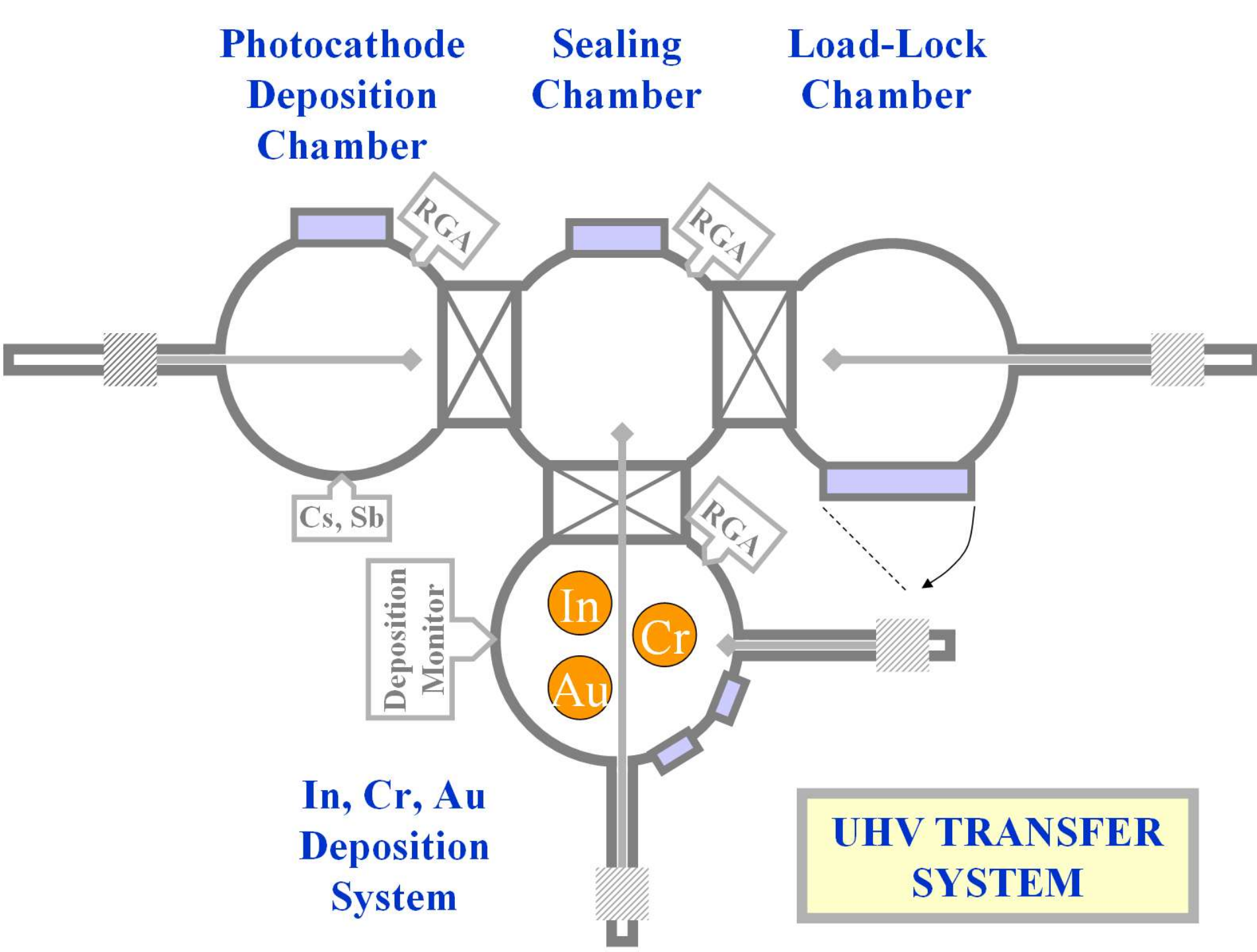
OBJECTIVES

1. PRODUCTION-LINE-FRIENDLY DESIGN
2. ~100% GLASS or QUARTZ
3. NO DYNODES
4. NO METALS (except for thin films of Cr, Au, In, and the photocathode)
5. NO WIRE FEEDTHROUGHS
6. FLAT-ON-FLAT GLASS-GLASS SEALING WITH A THIN INDIUM FILM
7. OPEN ARCHITECTURE (essential for in-the-production-line cleaning, evaporation, sealing)
8. COMPACT, ROBUST (vibration, pressure, accidental exposure to light)
9. NEW: SCALLABLE APPROACH TO MASS-PRODUCTION, and IN-HOUSE PRODUCTION

New Oxide-Free Indium Sealing Method

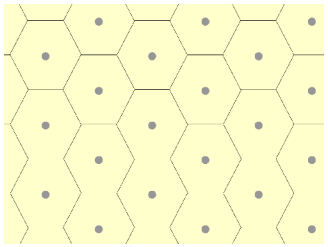


See NIM-A paper, D. Ferenc, E. Lorenz et al. 2006

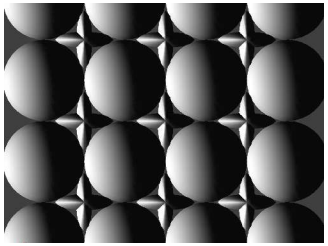

Photocathode Deposition Chamber
Sealing Chamber
Load-Lock Chamber
RGA
RGA
RGA
Cs, Sb
Deposition Monitor
In
Cr
Au
In, Cr, Au Deposition System
UHV TRANSFER SYSTEM

PHOTOSENSOR CONCEPTS

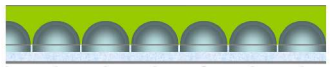
ReFerence - REFLECTION-MODE FLAT PANEL



ArcaLux - TRANSMISSION-MODE FLAT PANEL



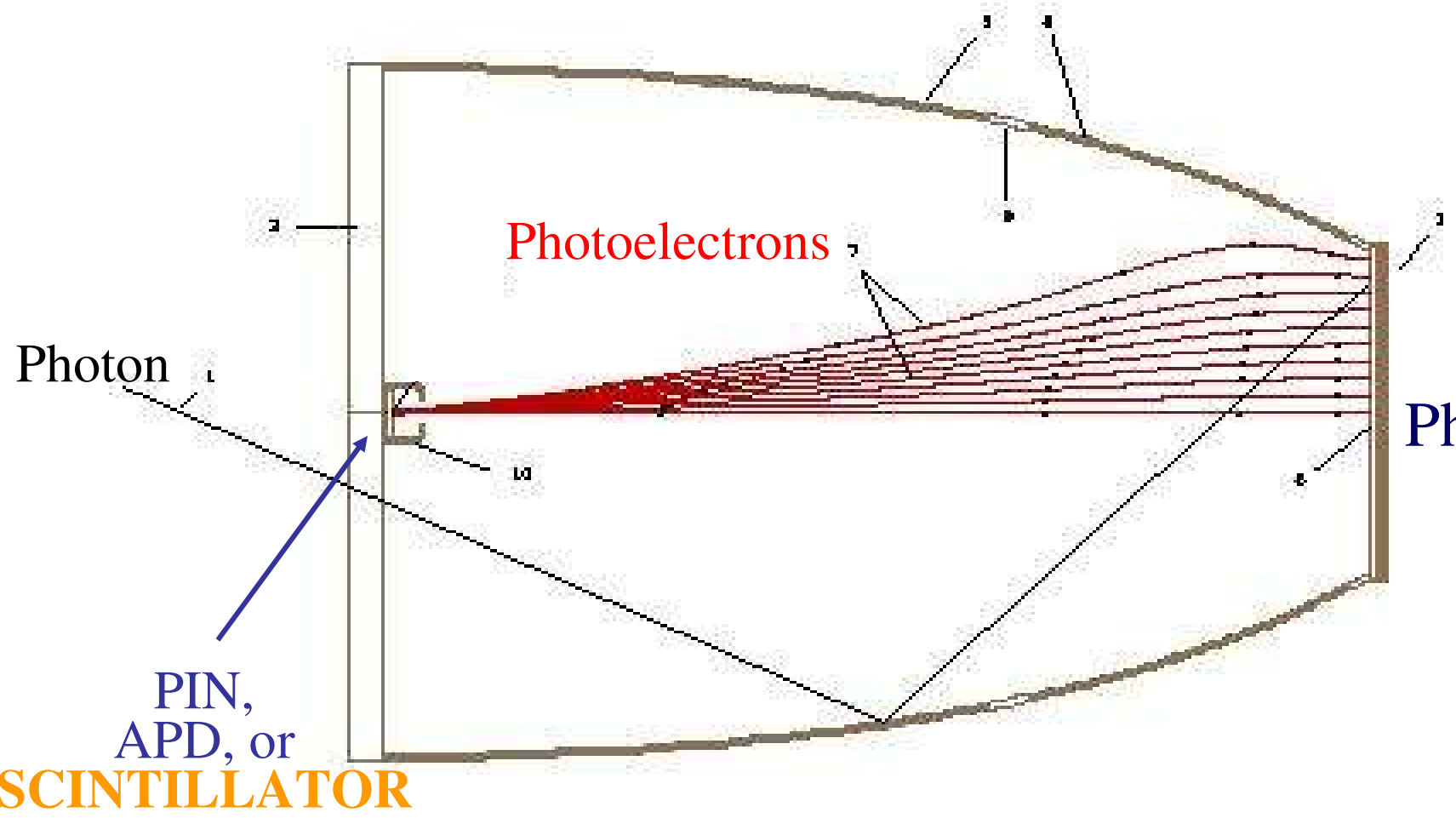
ABALONE - TRANSMISSION-MODE INDIVIDUAL HEMISPHERICAL PIXELS → FLAT PANEL; SCALLABLE PRODUCTION



ReFerence - REFLECTION-MODE FLAT PANEL

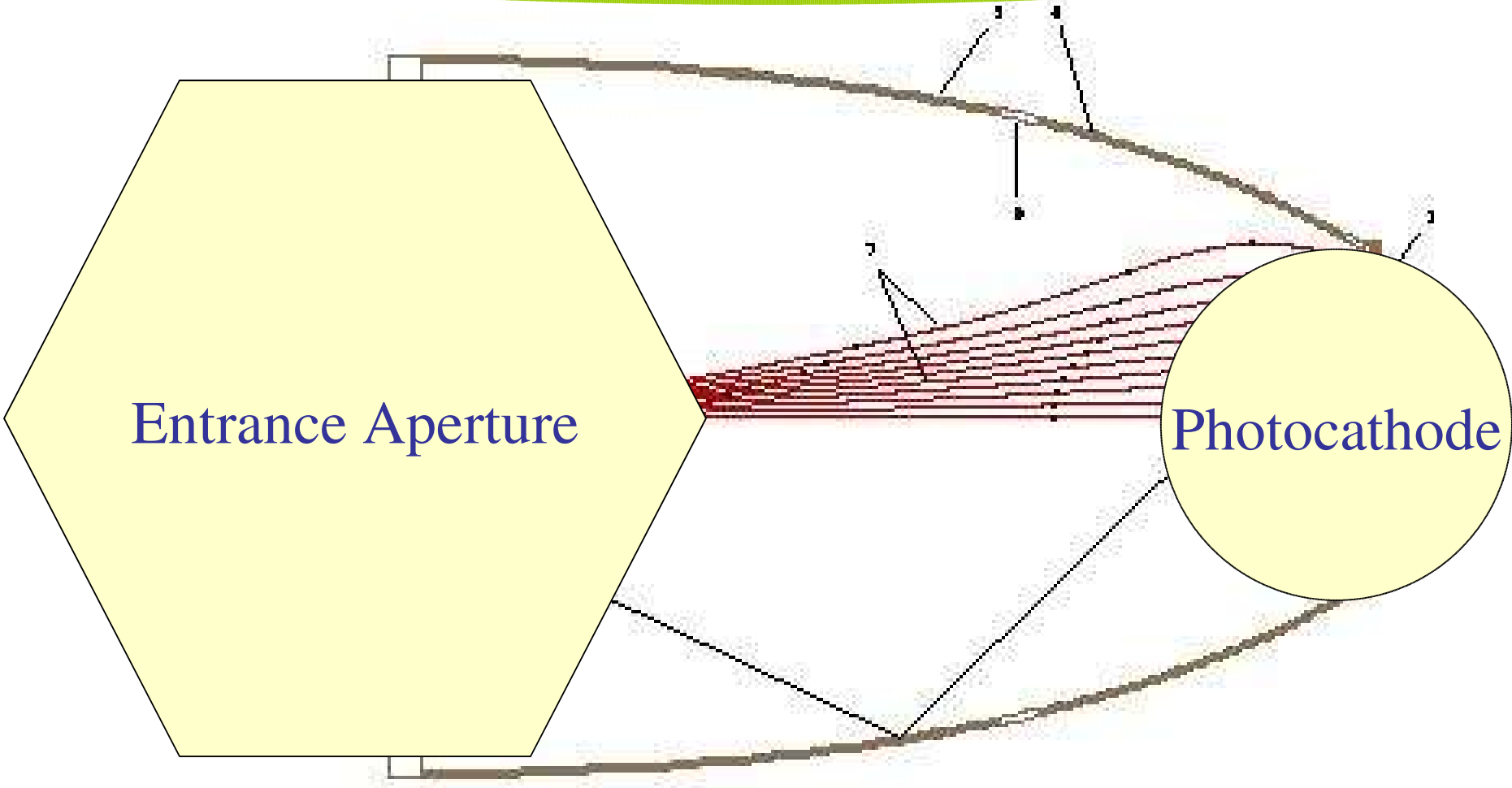
Ideal Light Concentrator

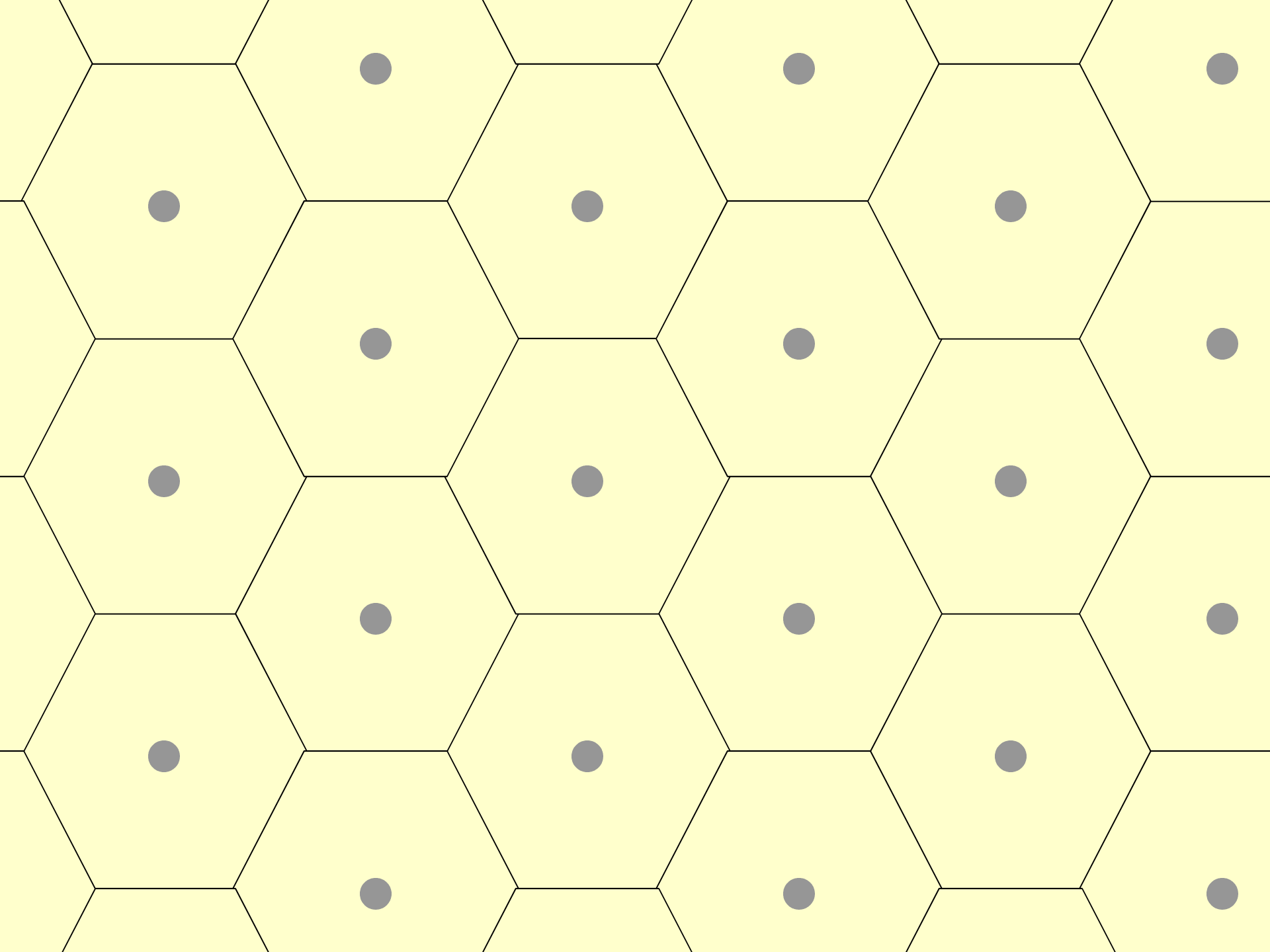
(takes the maximum of Liouville!)



Optimal Electron Lens

Very Important: Hexagonal Packing

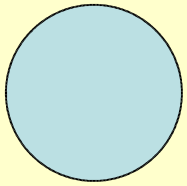




PROTOTYPE DEVELOPMENT

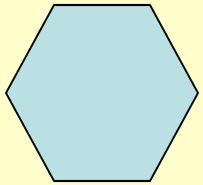
UNSEALED 1-PIXEL

CYLINDRIC



2001-2002

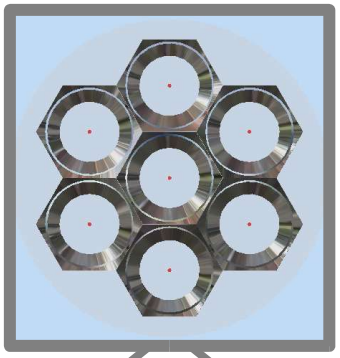
HEXAGONAL



2003

SEALED PANELS

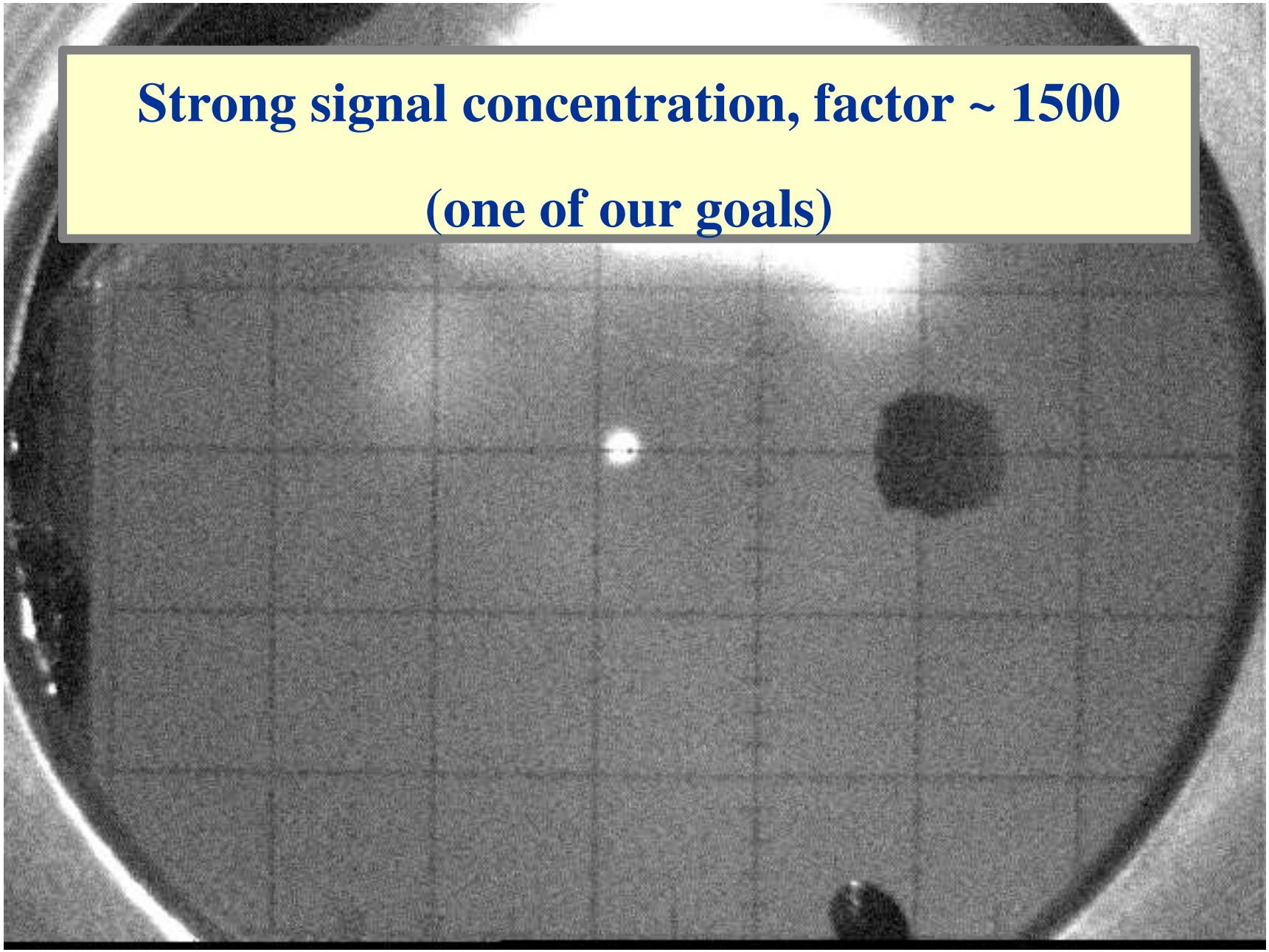
(7 pixels, 5 inch)



SEALED with In/Au

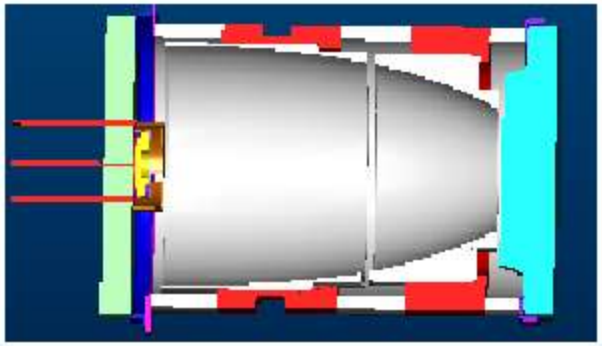
SEALED with SOLDER GLASS

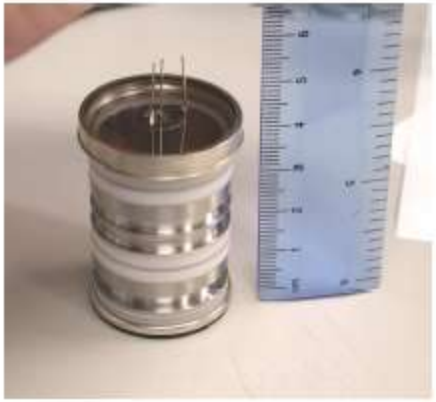
Equipment (Candescent, Litton Night Vision) ~$2M


Strong signal concentration, factor ~ 1500
(one of our goals)

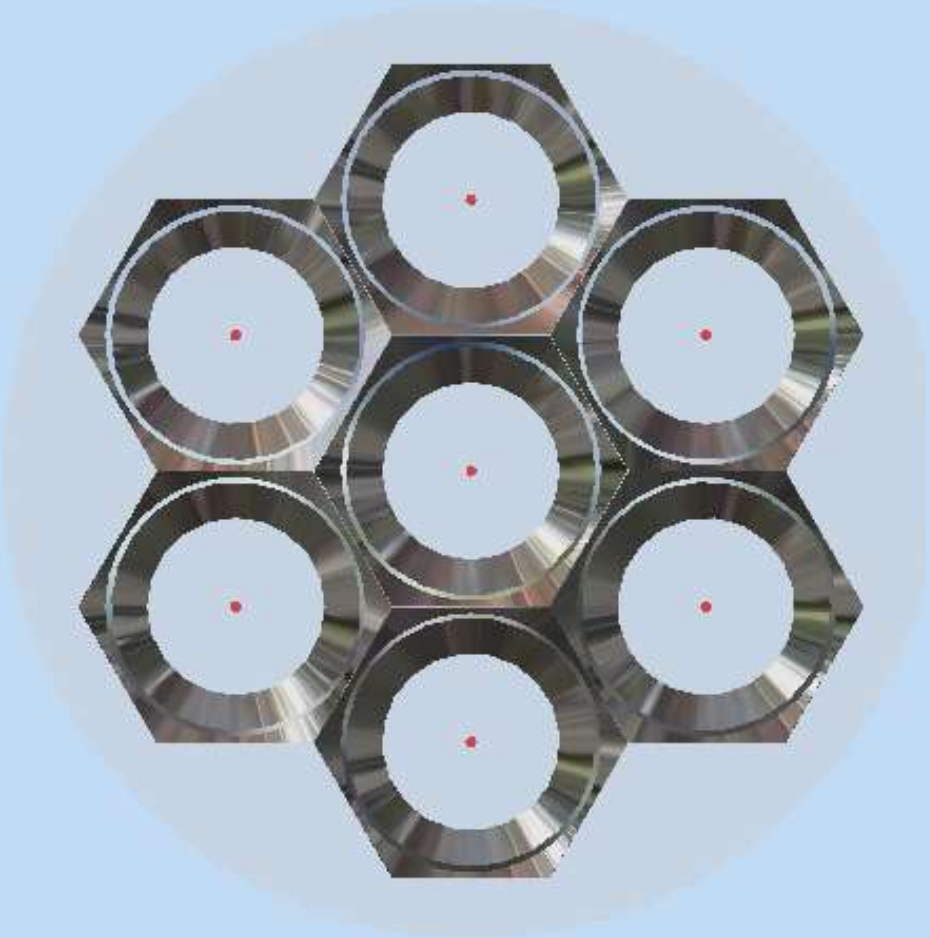
ReFerence Tube Design

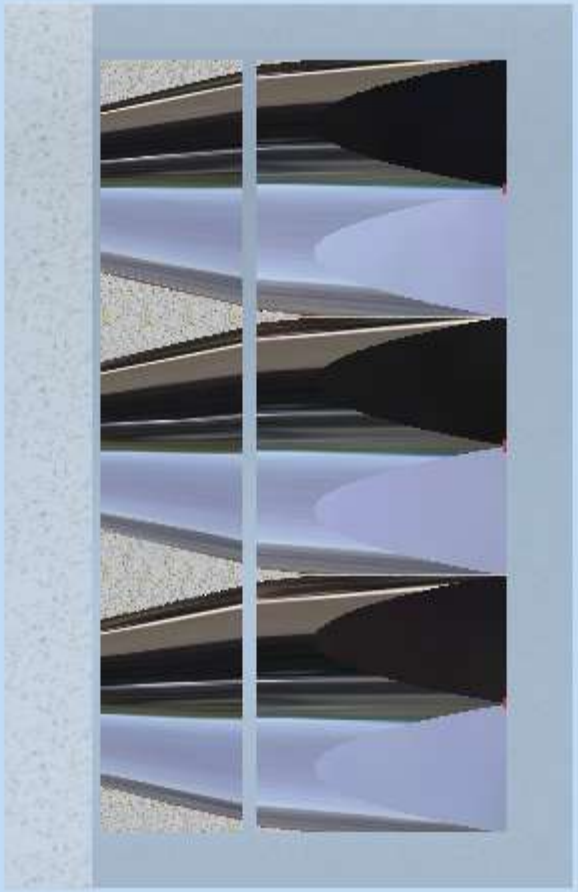
- Reflection mode GaAs cathode (12.5mm used)
- Sapphire input window 25mm aperture
- High voltage APD (API)
- Segmented Kovar CPCs for concentration and timing
- Size chosen to use standard parts and tooling
- Prototype device to test design concept with short time and internal funding
- Anticipate improved external QE 300-400nm and good QE out to 900nm





ReFerence Panel Prototype (under construction)



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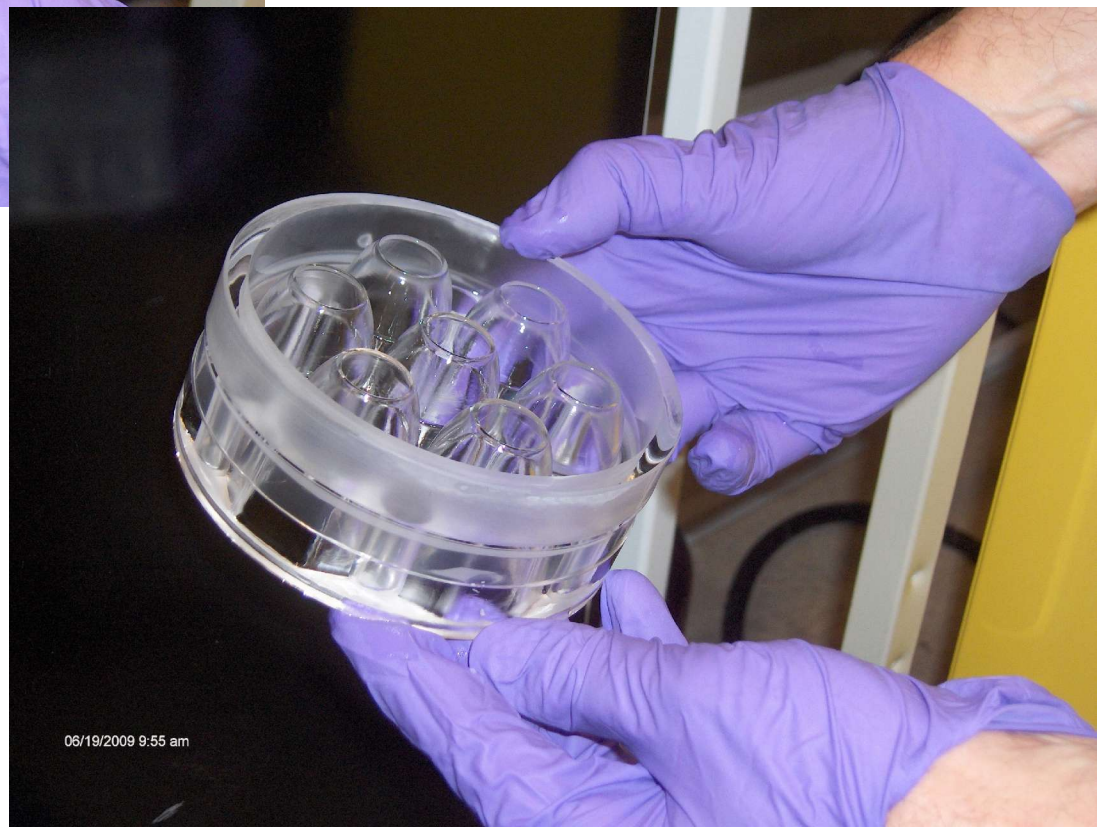
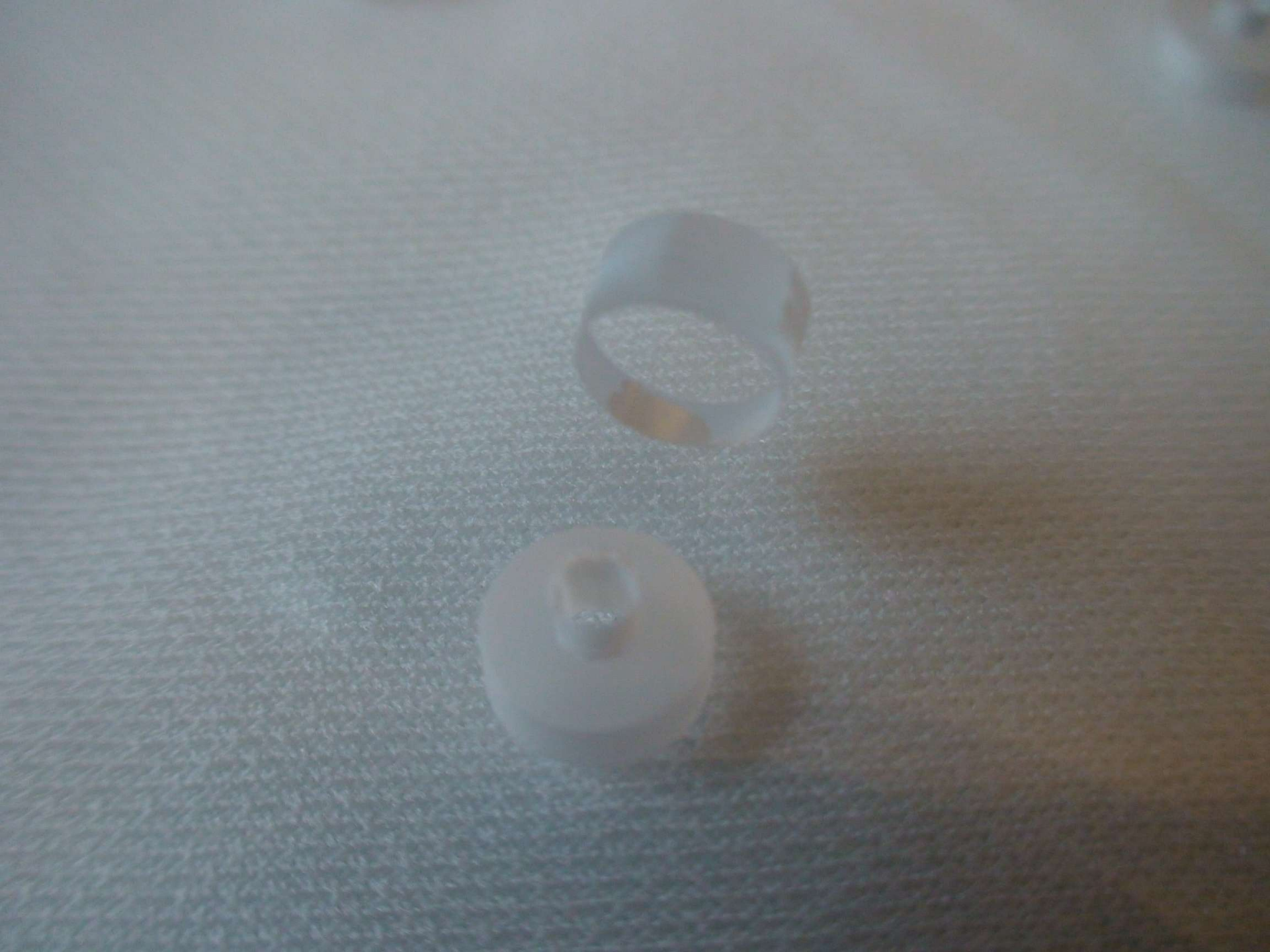

06/19/2009 9:55 am


DANGER
HIGH
TAGE
OFF
06/20/2009 7:09 am



‘ArcaLux’

(*lat*. light box)

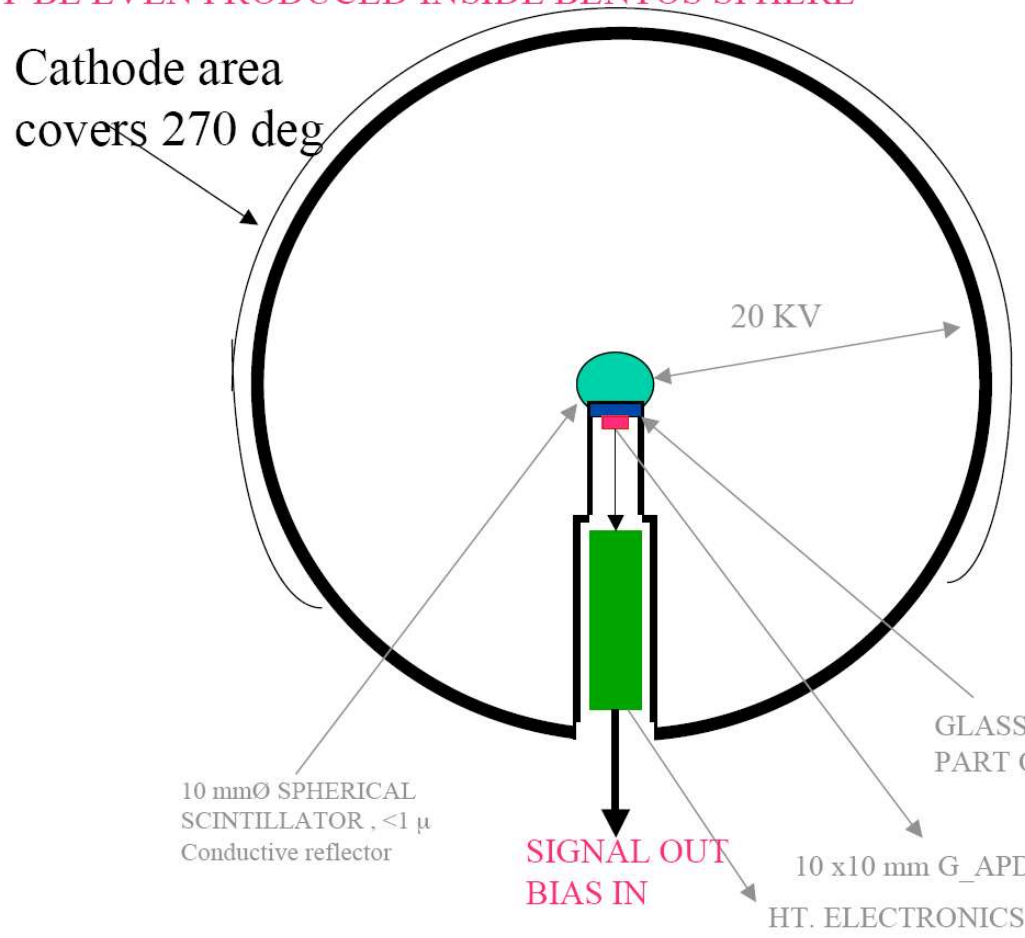
- **Full angular acceptance**
- **Perfect optical coupling to thick layers of water or scintillator**
- **High ambient pressure**
- **Extreme robustness**

➔ **SPHERICAL CONFIGURATION**

- **Immune to accidental exposure to high light intensities**

➔ **LIGHT AMPLIFIER (G-APDS)**

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.**

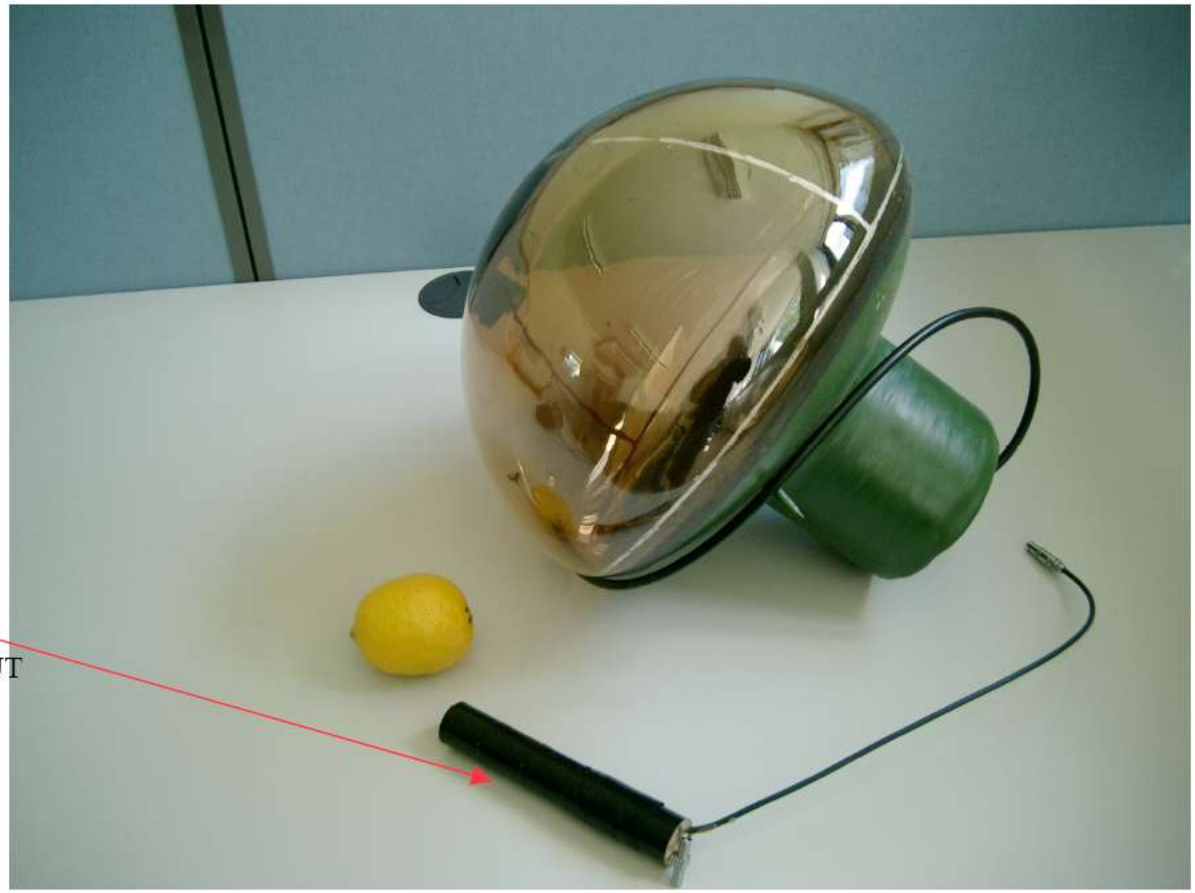
THE QUASAR

IMPROVED VERSION OF THE SMART PMT

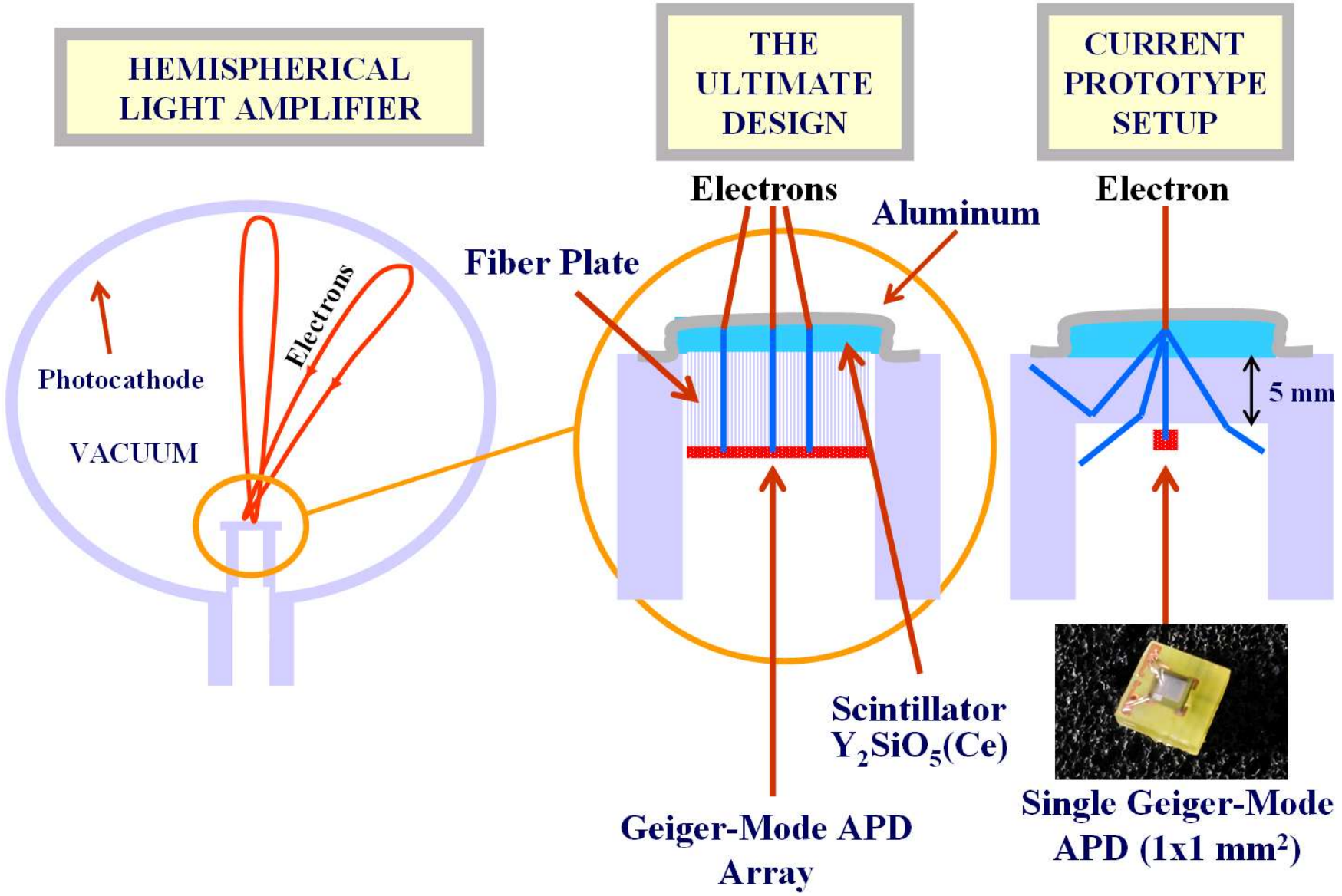
- LARGE ACTIVE AREA/TOTAL VOLUME
- SYMMETRIC PHOTOELECTRON COLLECTION
- PRACTICALLY 100%PHOTOELECTRON COLL.EFFICIENCY
- NO NEED FOR BLEEDER CURRENT -> VERY LOW HT POWER
- ALREADY IN LONGTERM USE IN LAKE BAIKAL
- RELATIVELY CHEAP
- CAN DETECT SINGLE PHOTOELECTRONS,
- F-FACTOR ≈1.3

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

THE FOLLOWING TESTS HAVE BEEN CARRIED OUT WITH A QUASAR

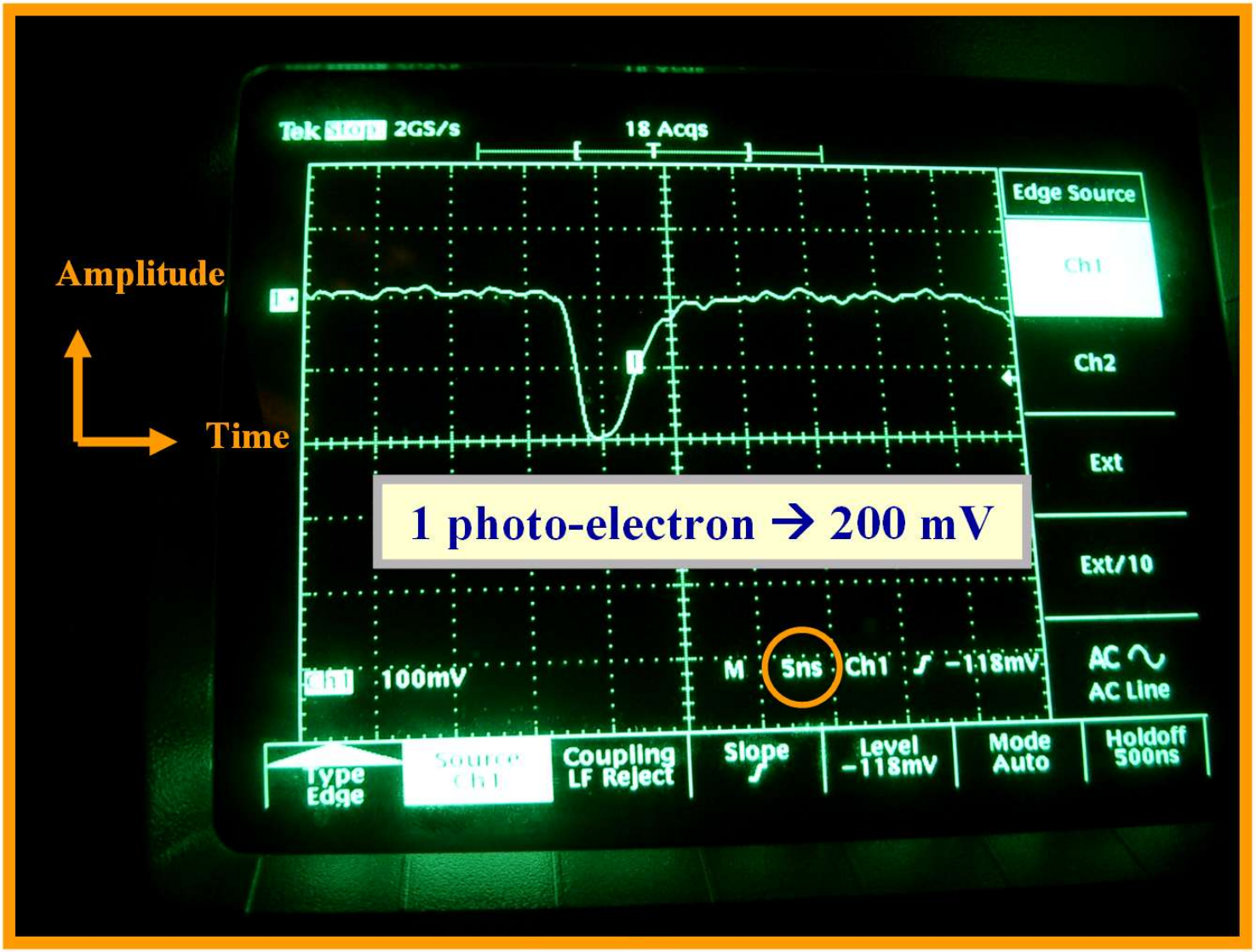


SECONDARY PMT TO READ OUT CRYSTAL



E. Lorenz, D. Ferenc, Beaune 2005, MIMA

A Typical Single-Photon Signal in the Geiger-mode APD



E. Lorenz, D. Ferenc, Beaune 2005, MIMA

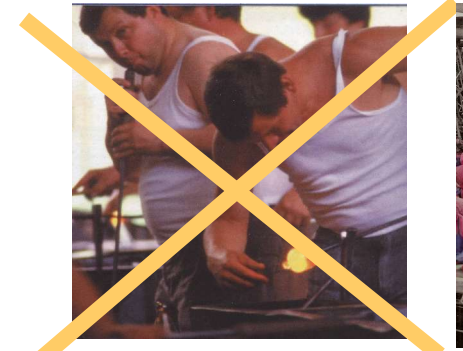
Mr. ◯ & Mrs. ▭

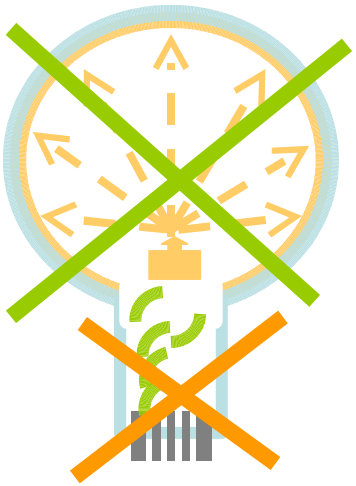
Mass production

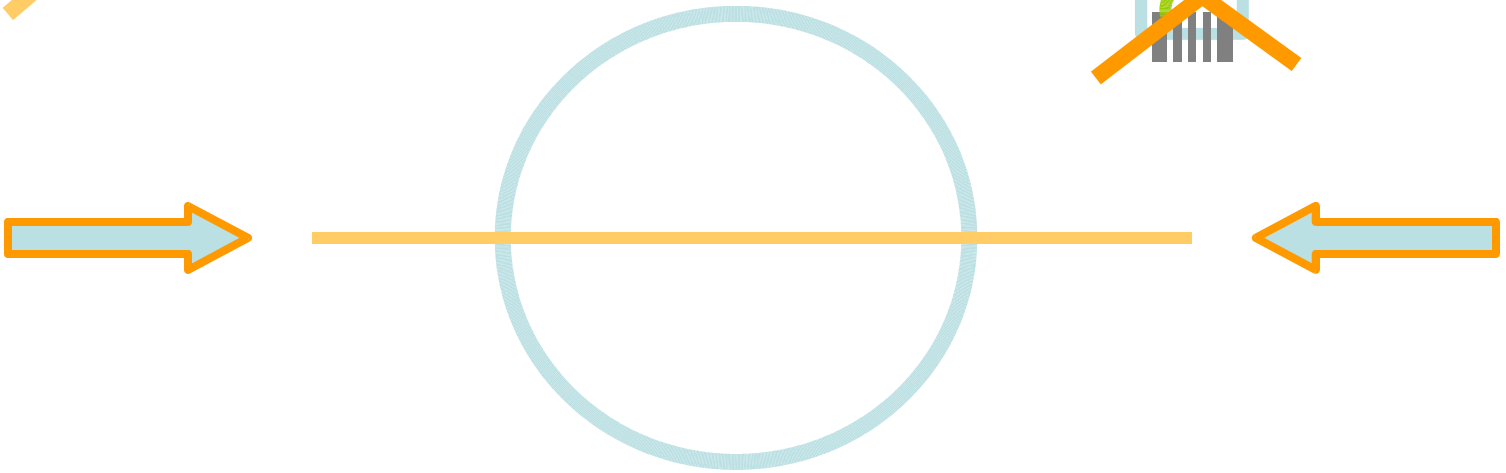
High performance

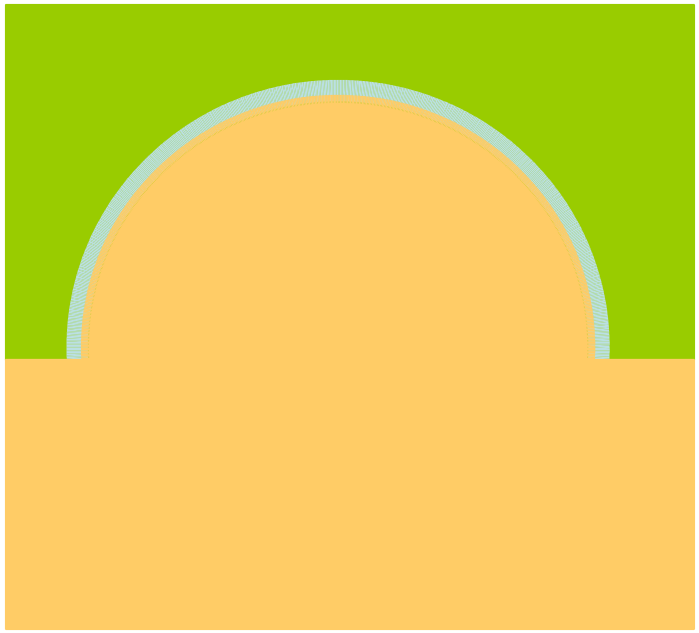
COMPONENTS:
Industrially mass-produced

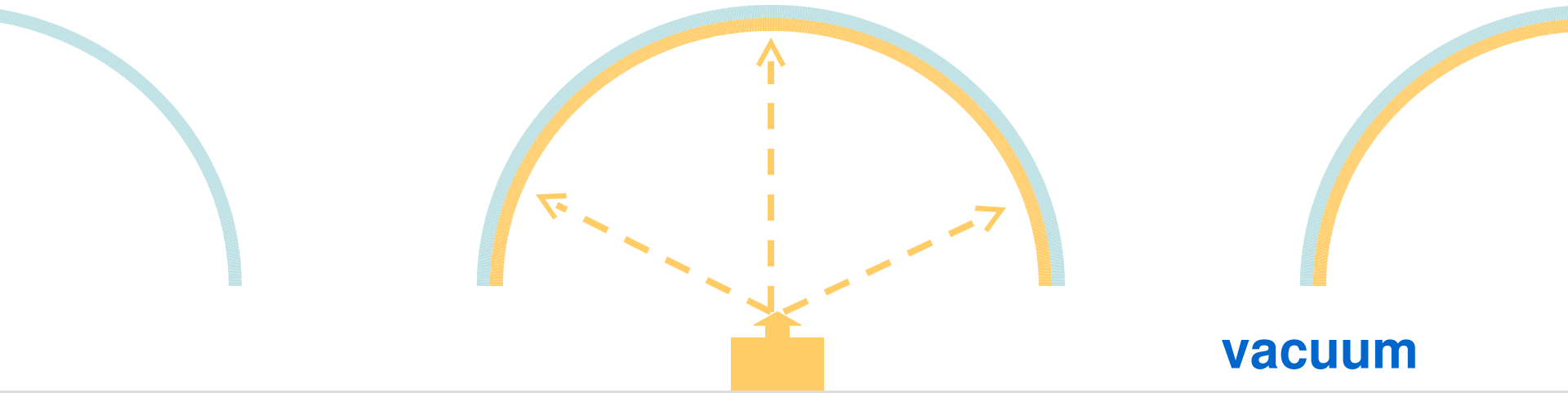
ASSEMBLY:
Production-line










vacuum

?

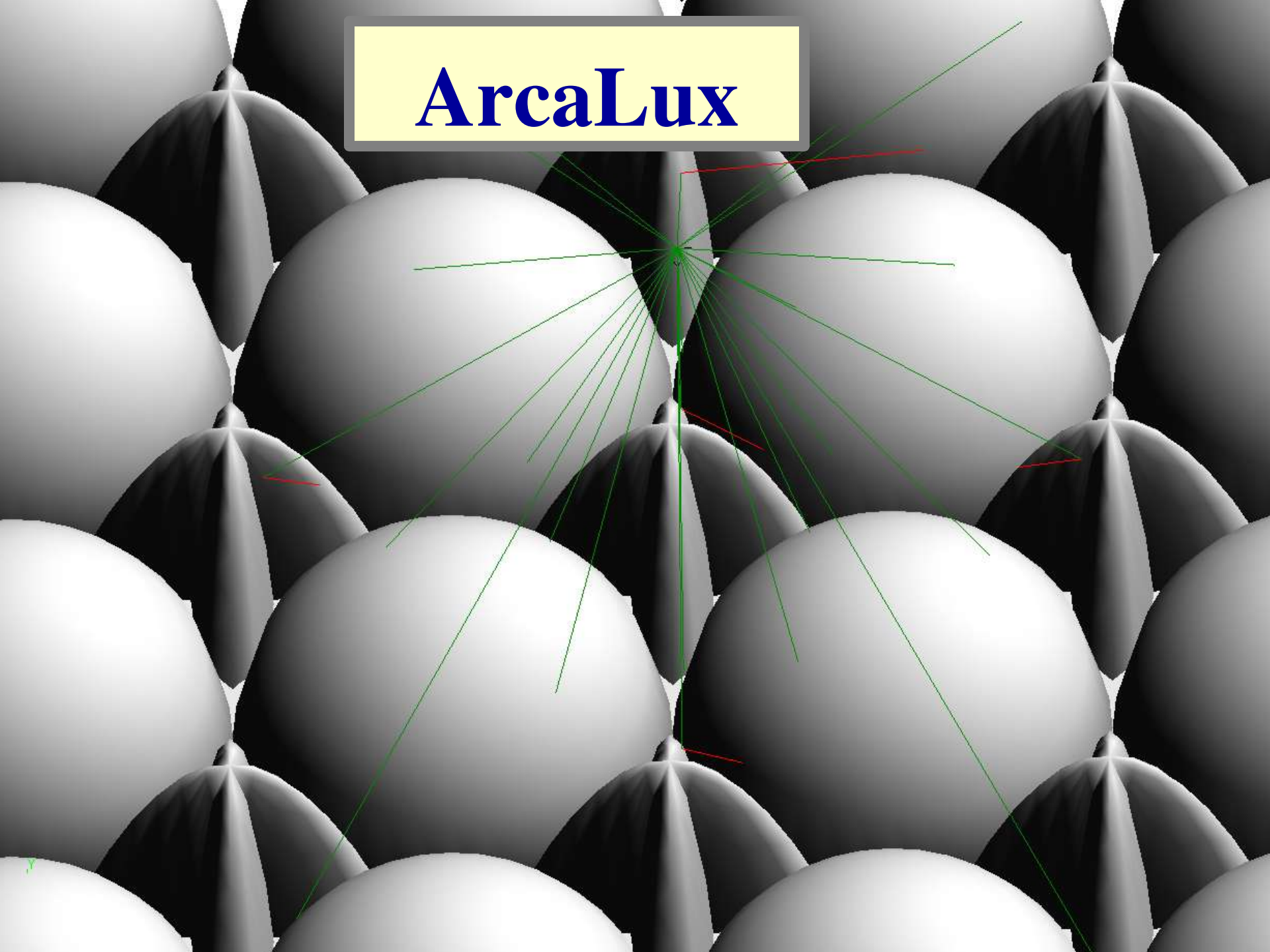
Special marriage:

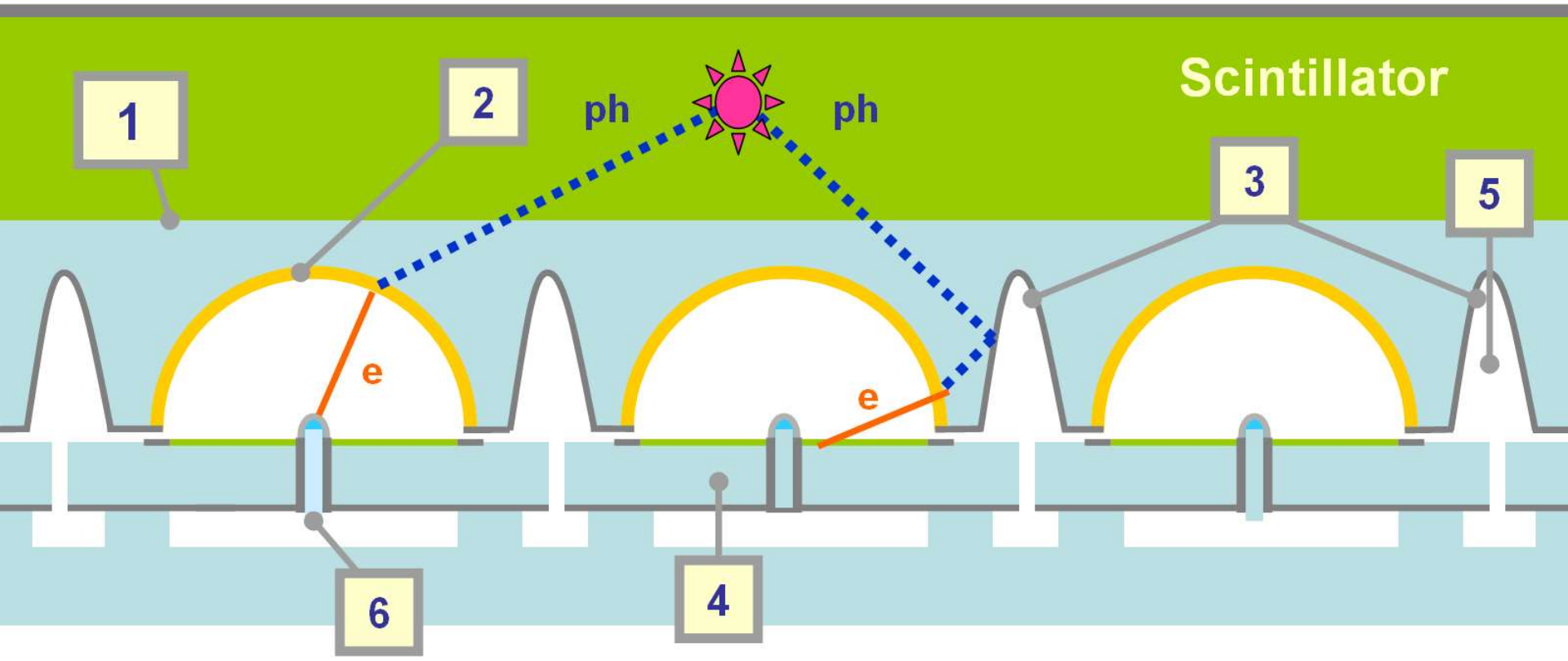
~ 0% dead area

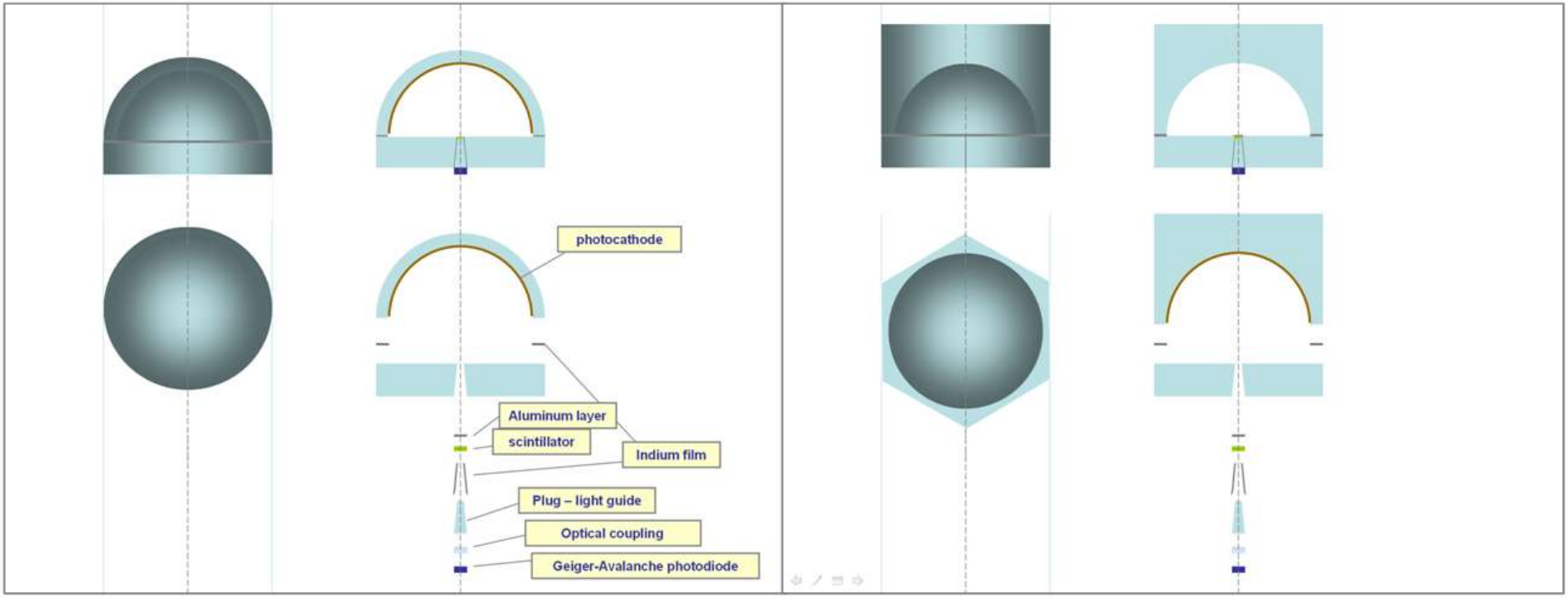
Long-lasting – the internal pollution - internally absorbed

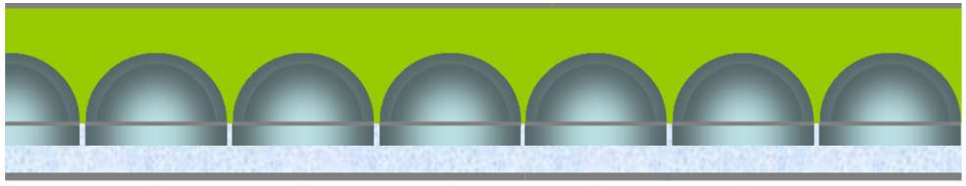
Highly resistant to pressure from outside

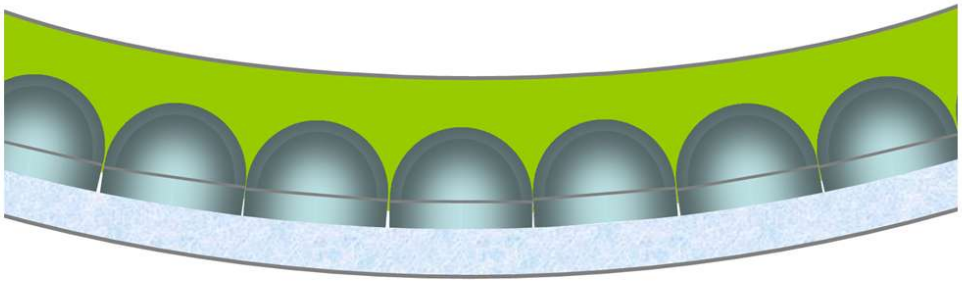
Ready for mass-production


ArcaLux


Scintillator
1
2
ph
ph
3
5
e
e
6
4


photocathode
Aluminum layer
scintillator
Indium film
Plug – light guide
Optical coupling
Geiger-Avalanche photodiode





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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:

Anne Nilsson

Product dimensions

Diameter: 5 "
Height: 2 "

Diameter: 12 cm
Height: 6 cm

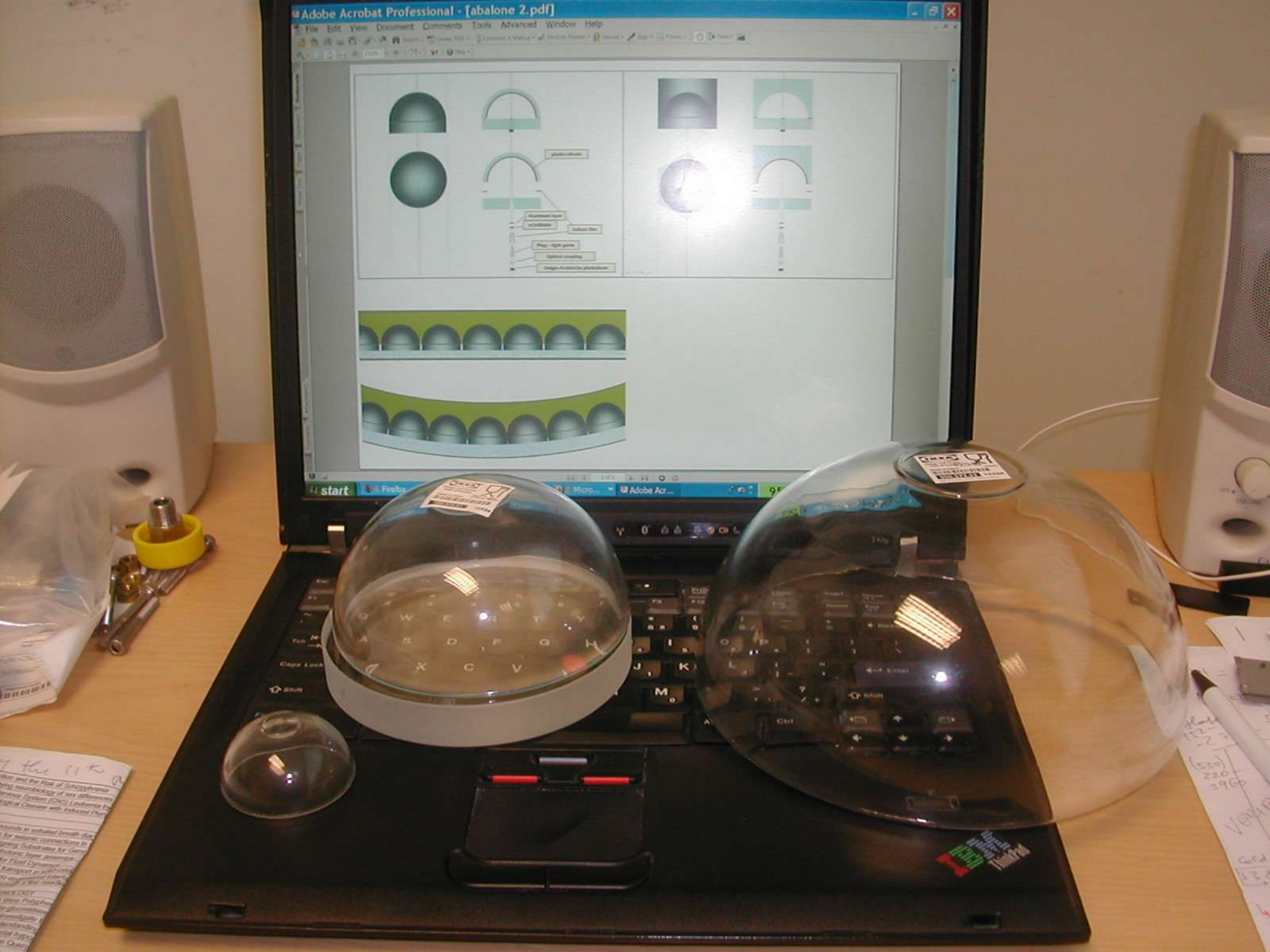
care instructions

Dishwasher-safe.

product description & measurements

Glass

package measurements & weight
(1 packages in total)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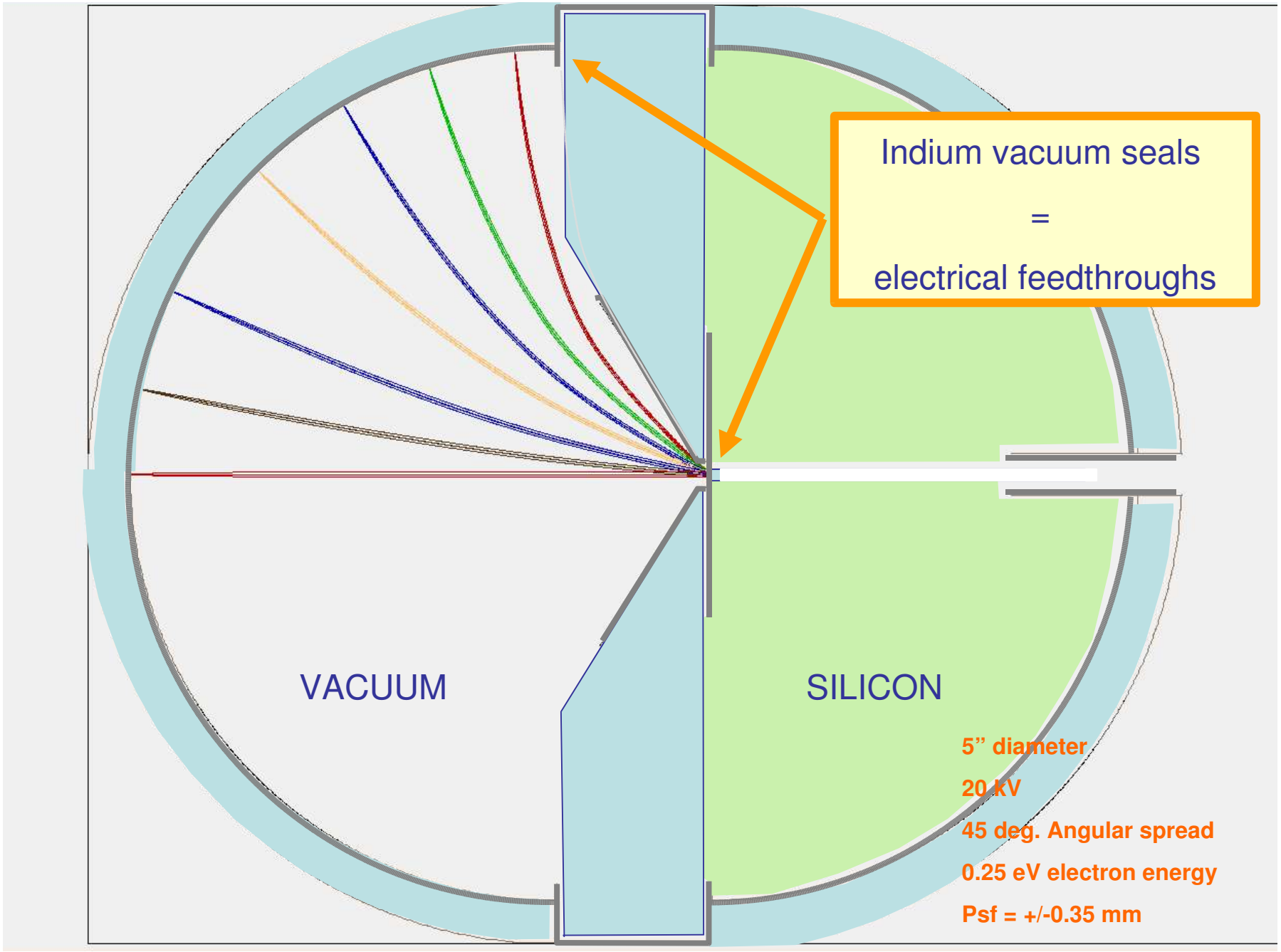
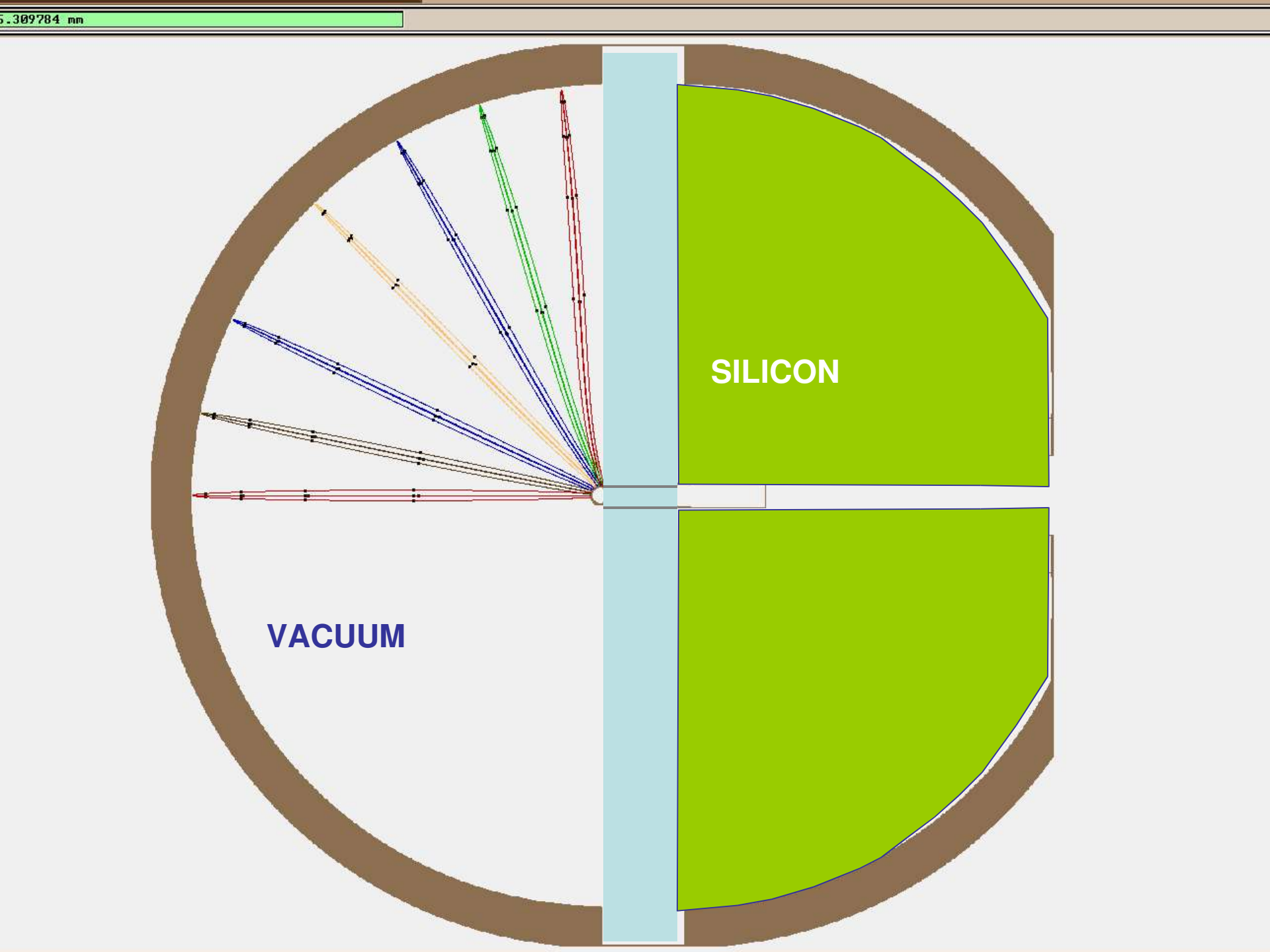
File Edit View Document Comments Tools Advanced Window Help
start


Indium vacuum seals
=
electrical feedthroughs
VACUUM
SILICON
5” diameter
20 kV
45 deg. Angular spread
0.25 eV electron energy
Psf = +/-0.35 mm


5.309784 mm
SILICON
VACUUM

OBJECTIVES

1. PRODUCTION-LINE-FRIENDLY DESIGN
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5. NO WIRE FEEDTHROUGHS
6. FLAT-ON-FLAT GLASS-GLASS SEALING WITH A THIN INDIUM FILM
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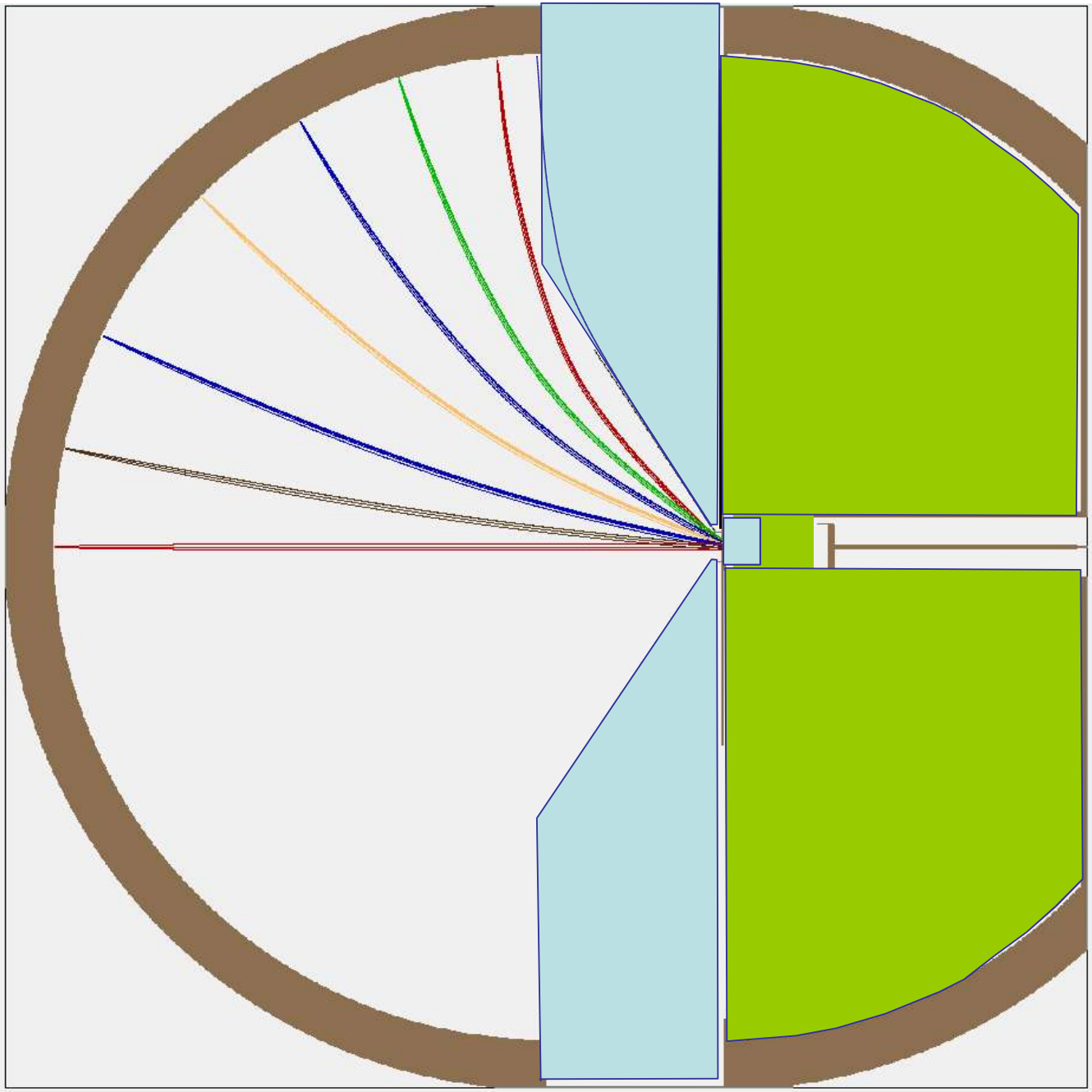
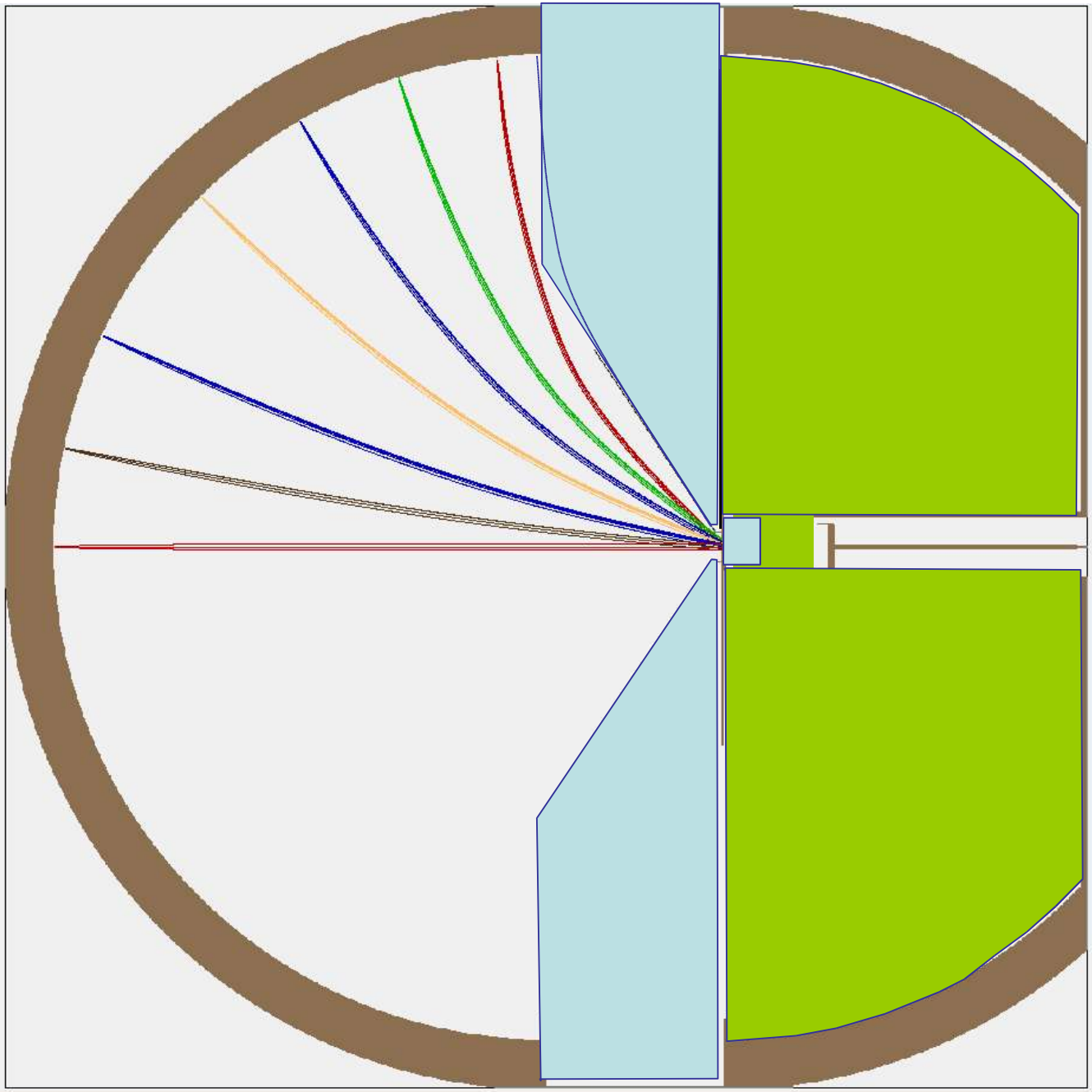
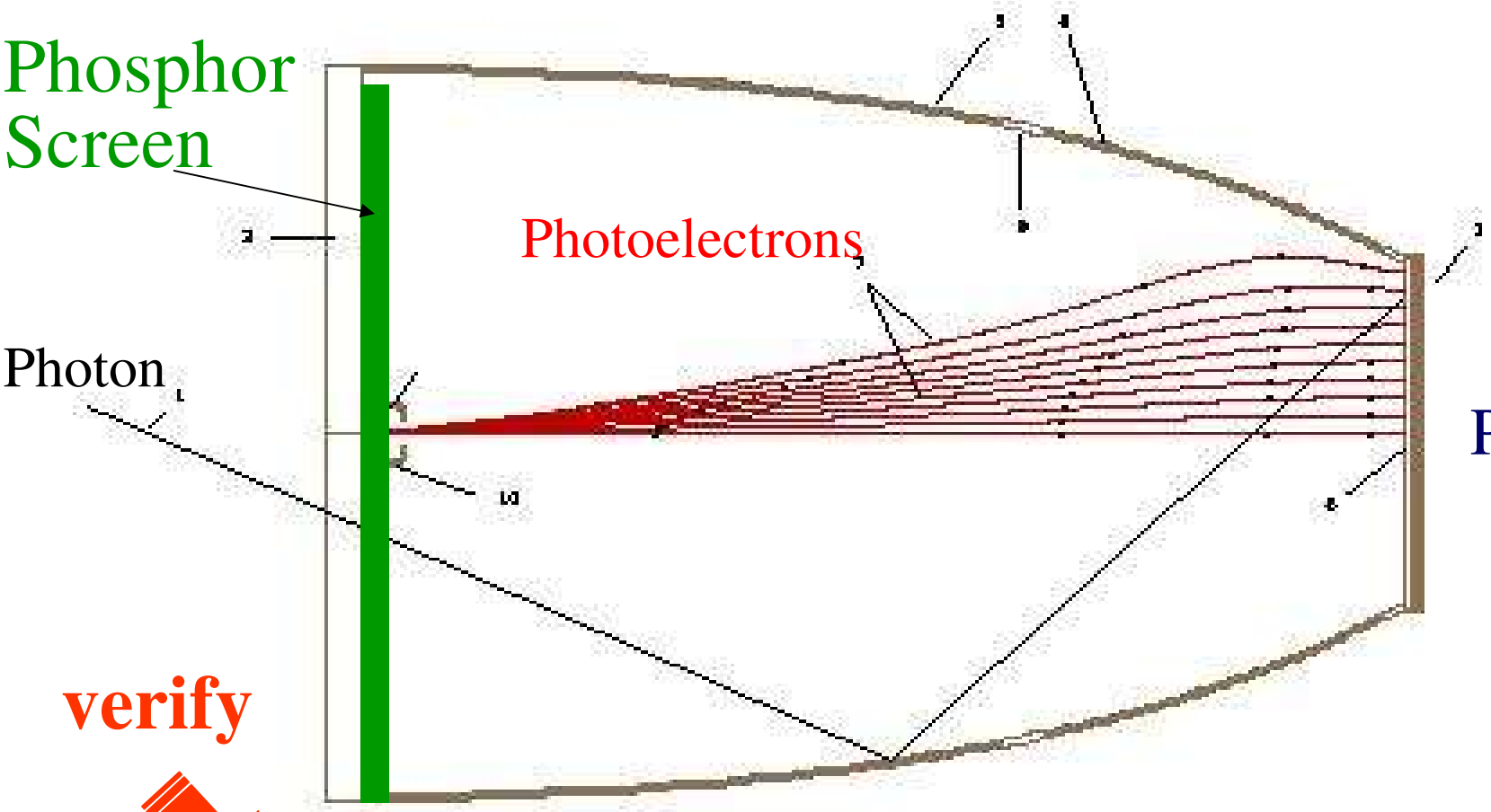
9. NEW: SCALLABLE APPROACH TO MASS-PRODUCTION, and IN-HOUSE PRODUCTION



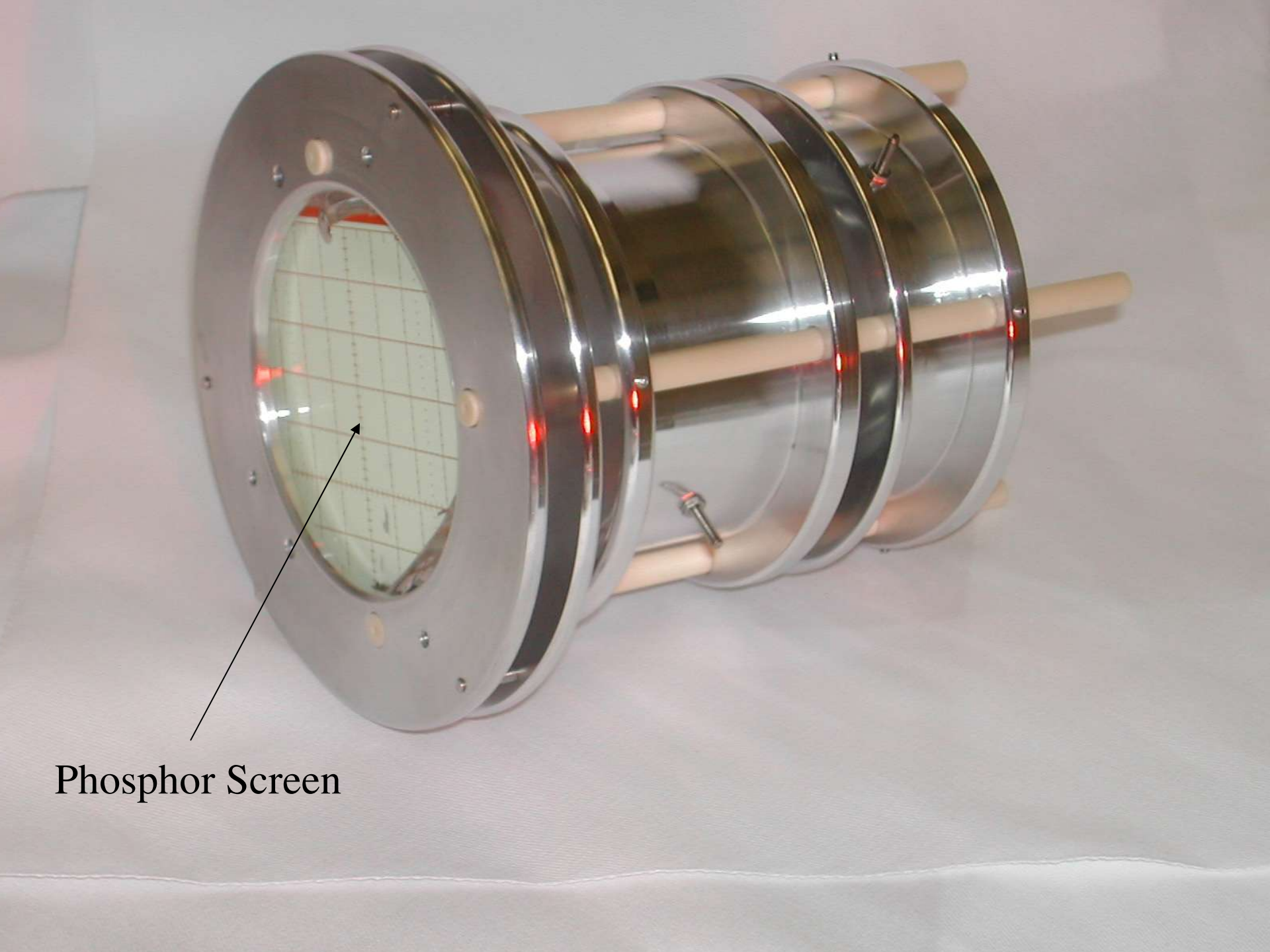


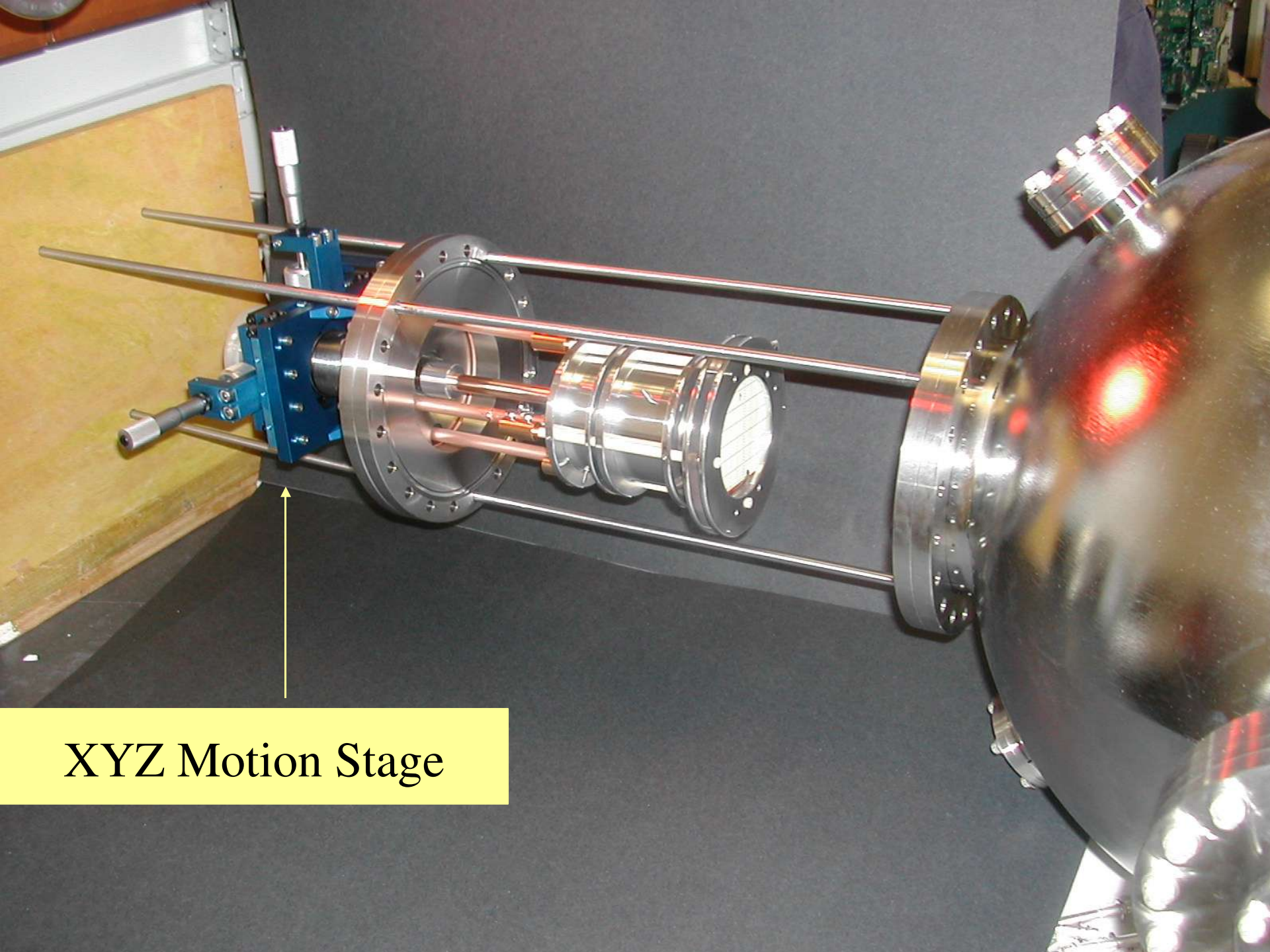
Ideal Light Concentrator = OK!

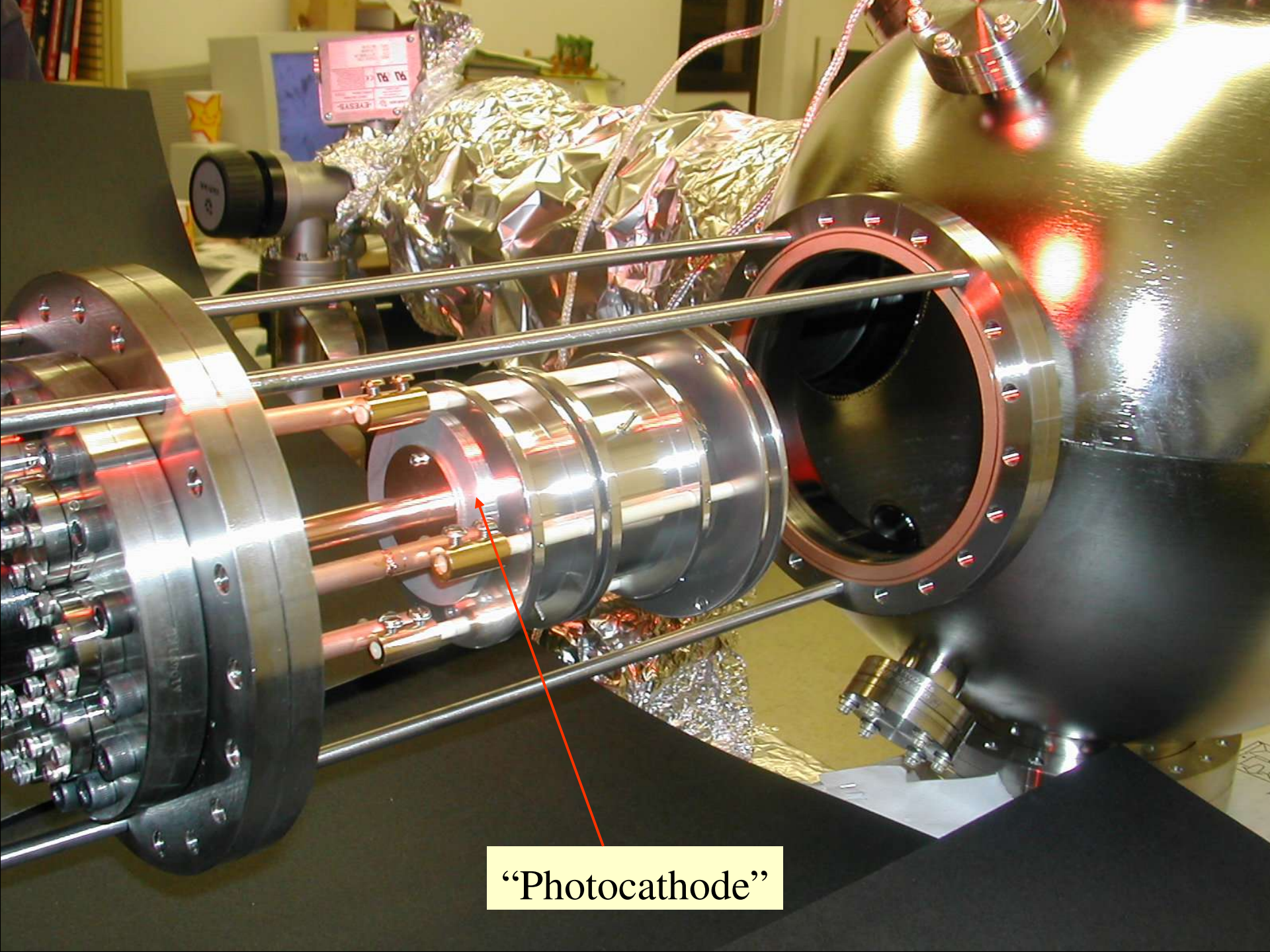


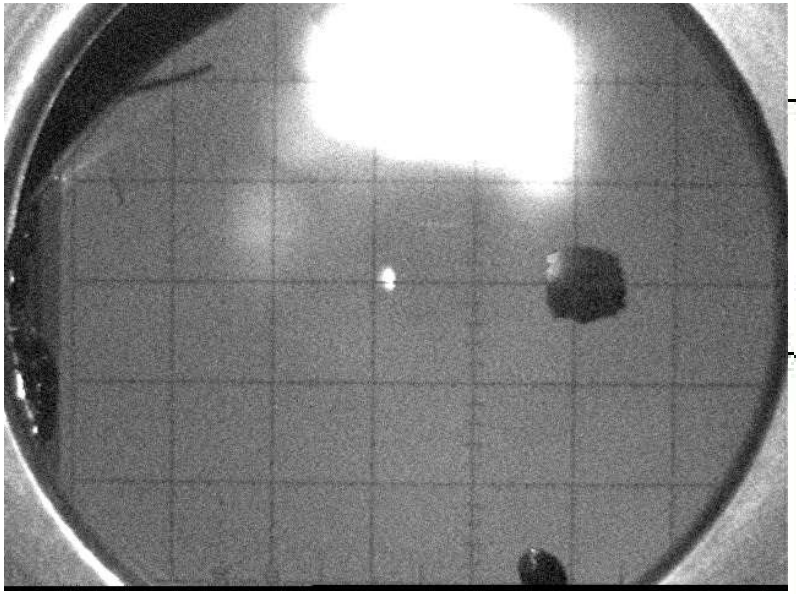
verify

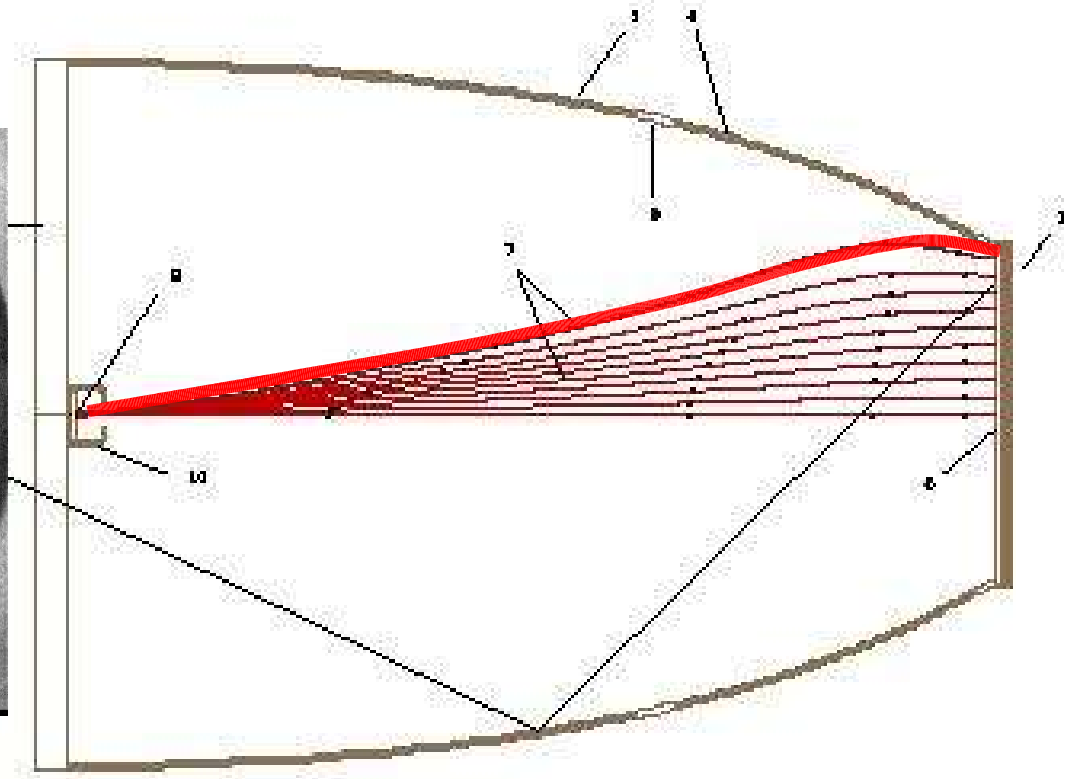
Optimal Electron Lens

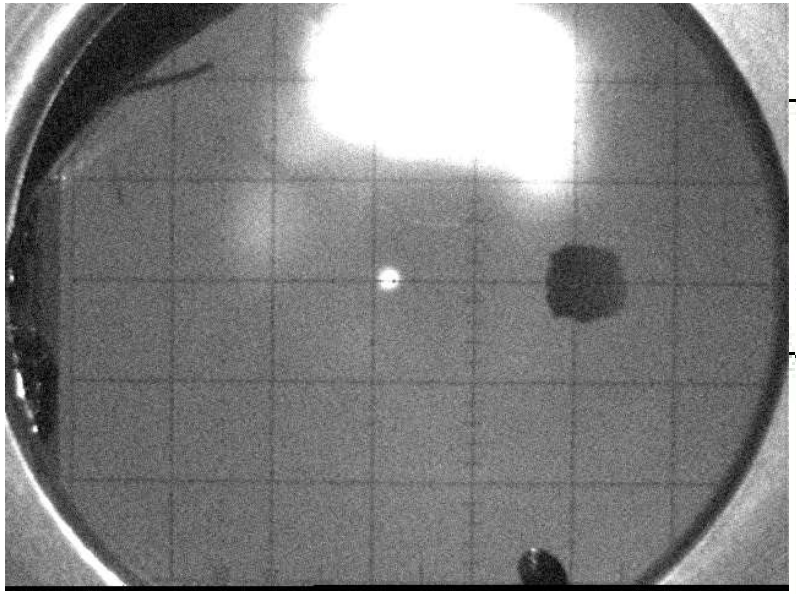

Phosphor Screen

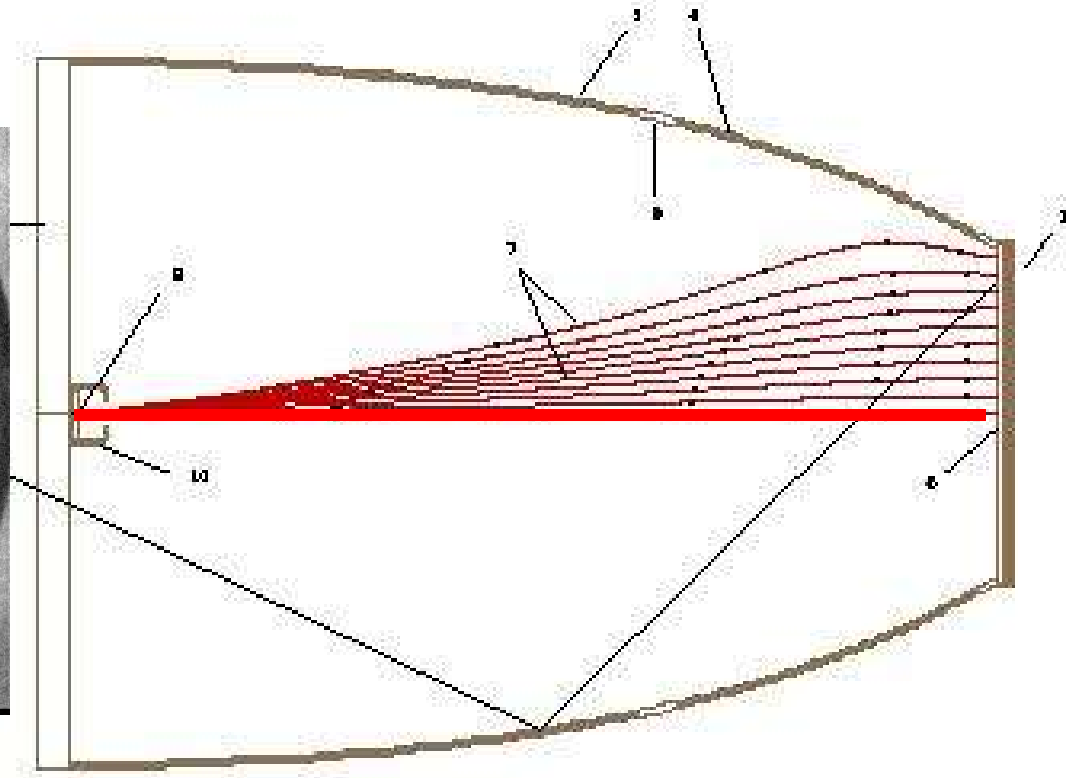

XYZ Motion Stage


“Photocathode”





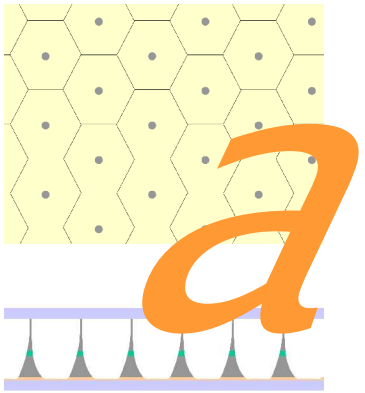




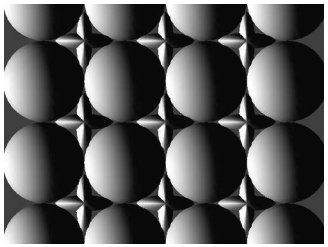
Conclusion

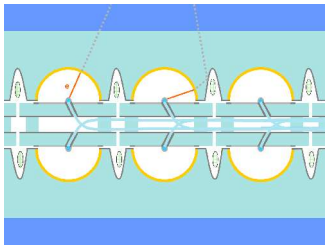
ULTIMATE:
FLAT-PANEL

ReFerence

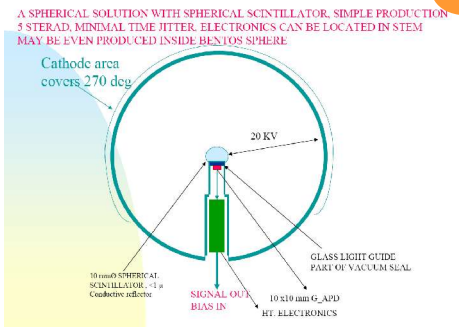


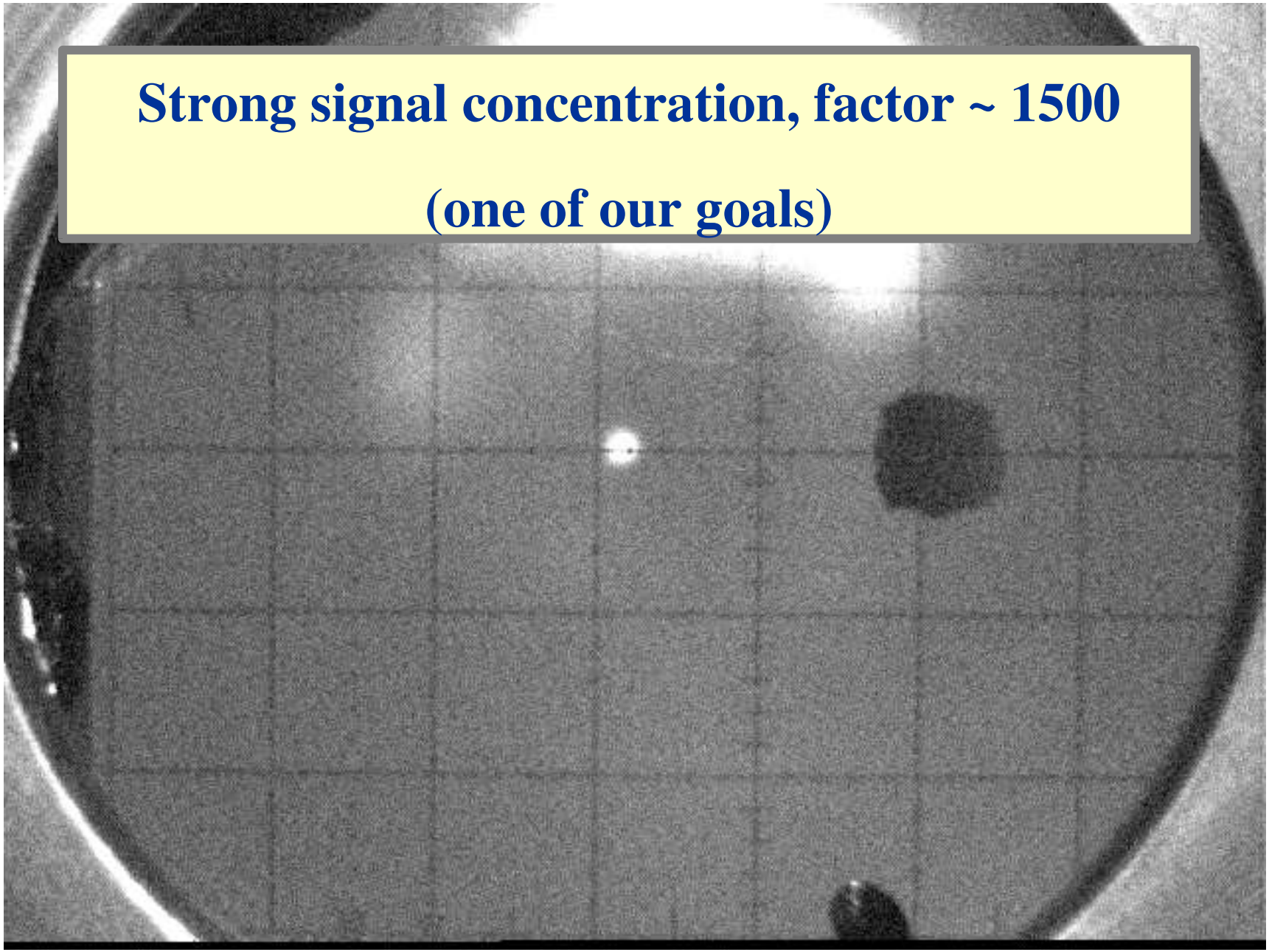
ArcaLux





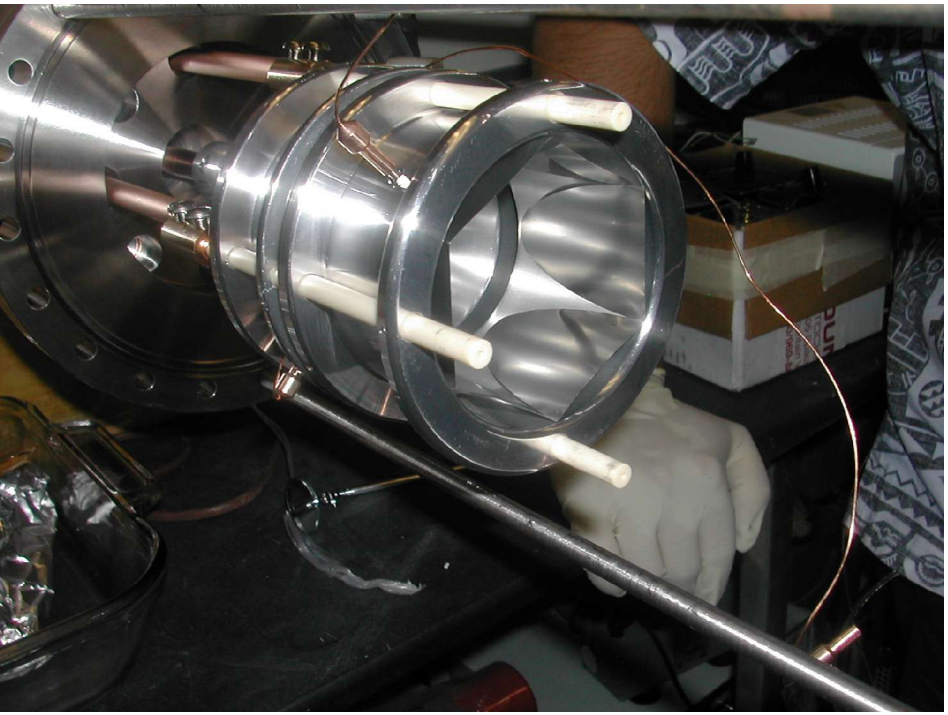
INTERMEDIATE:
HEMISPHERICAL
Light Amplifier

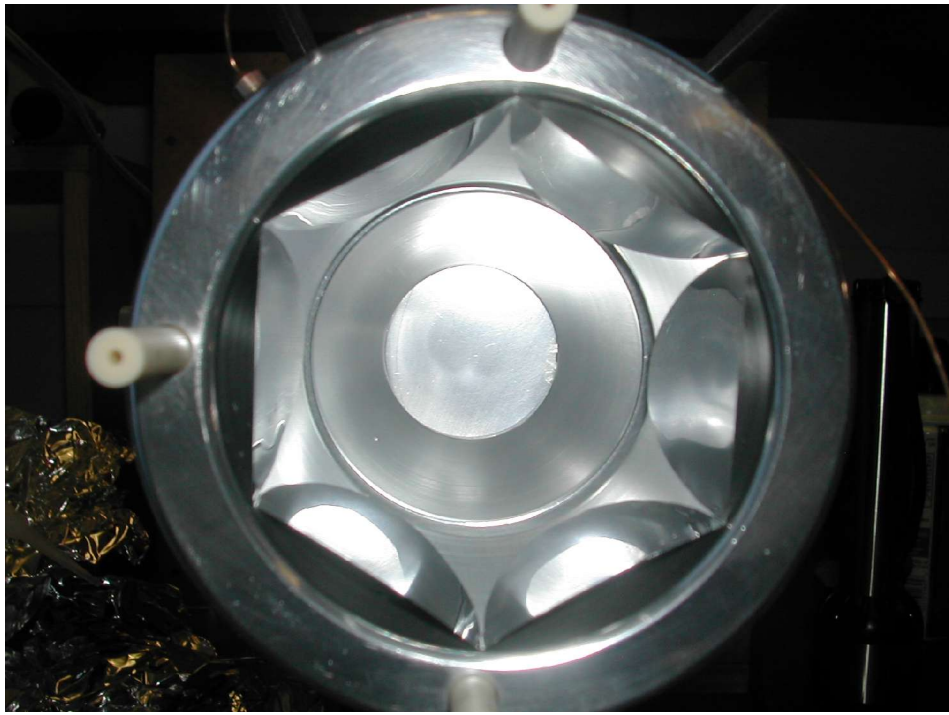



Strong signal concentration, factor ~ 1500
(one of our goals)

Currently Aluminum – ultimately GLASS

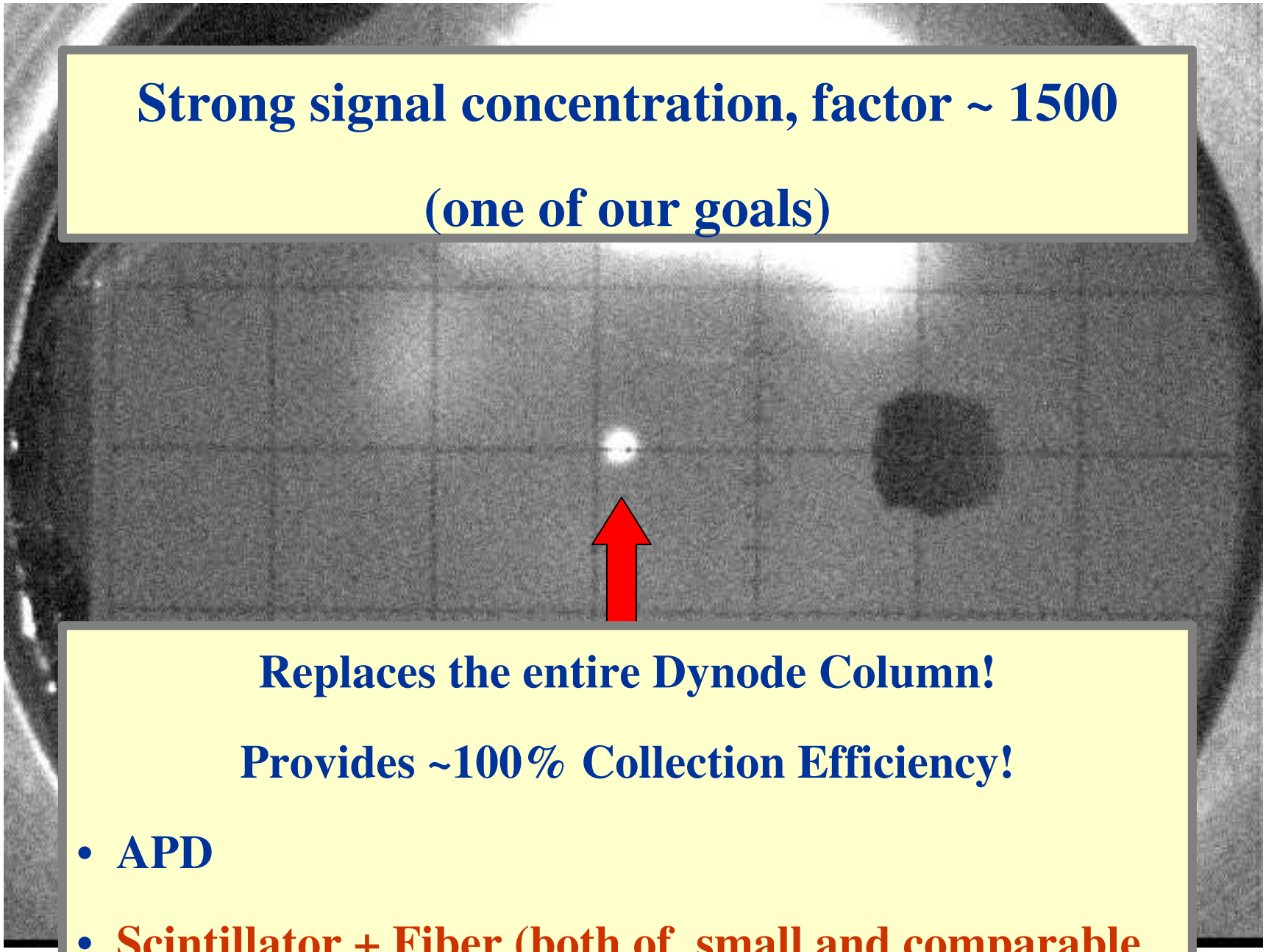
3rd ReFerence Prototype





3” diameter, single pixel

(successfully tested – see below)



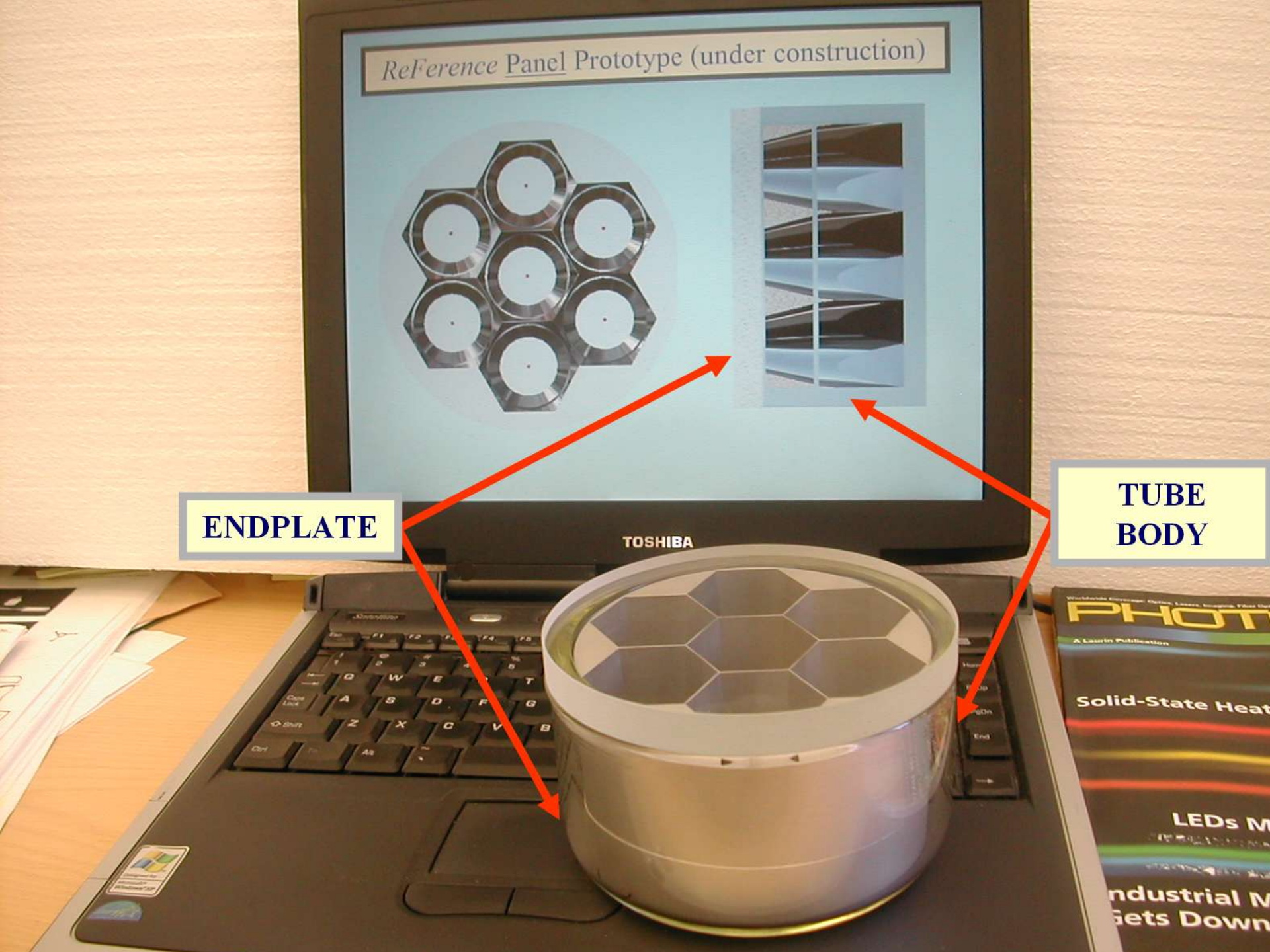
Strong signal concentration, factor ~ 1500

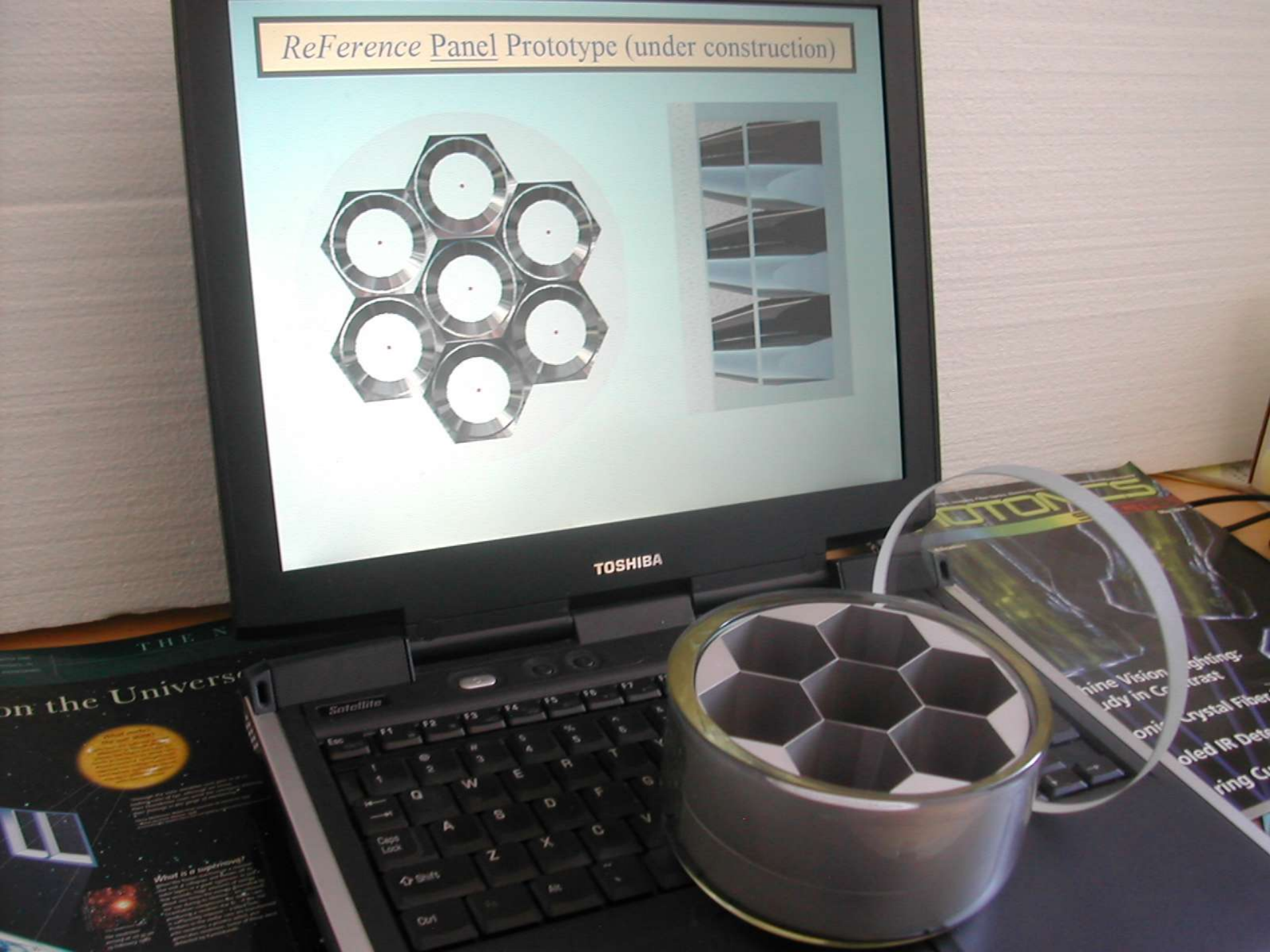
(one of our goals)

Replaces the entire Dynode Column!

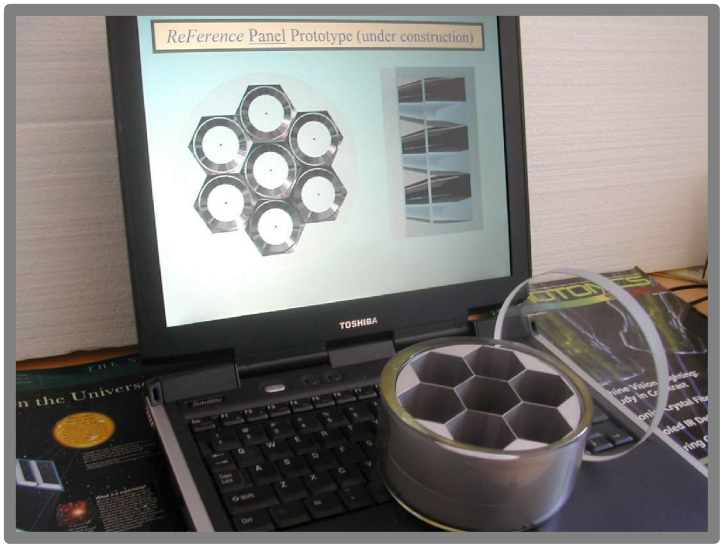
Provides ~100% Collection Efficiency!

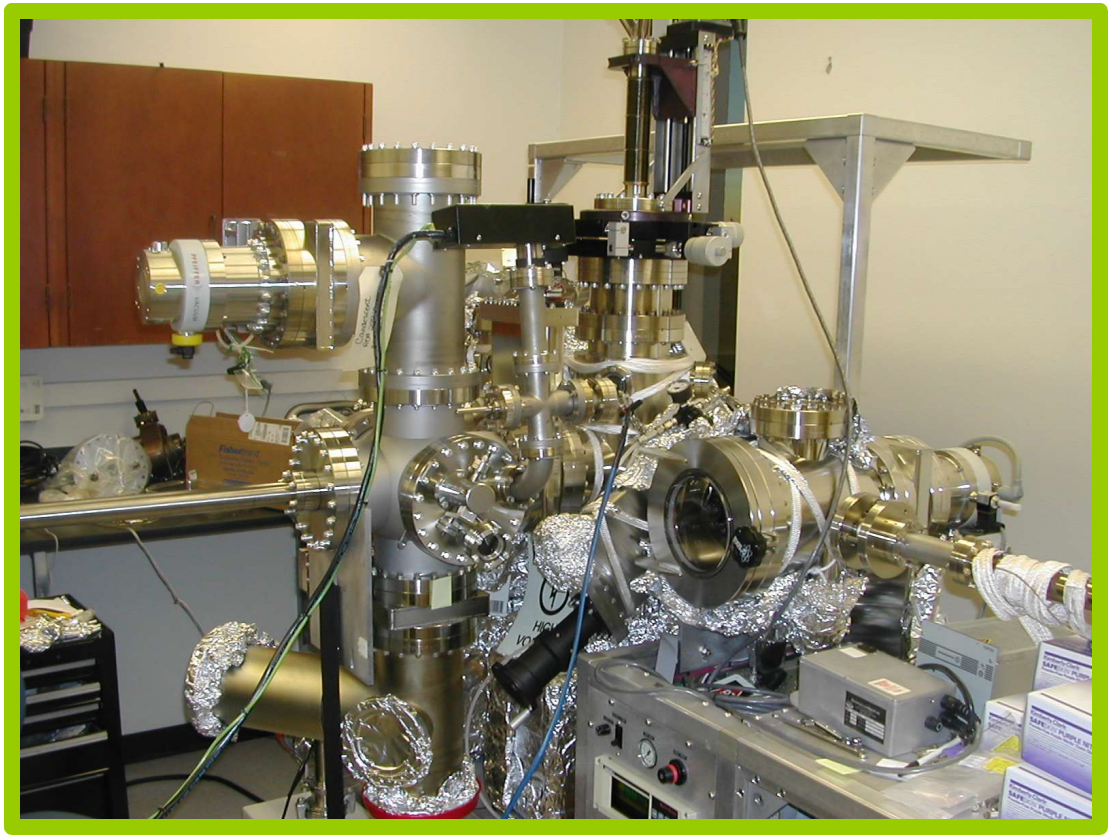
- **APD**
- **Scintillator + Fiber (both of small and comparable diameter → good coupling efficiency)**


ReFerence Panel Prototype (under construction)
ENDPLATE
TUBE BODY
TOSHIBA
Solid-State Heat
LEDs M
ndustrial M
Gets Down


ReFerence Panel Prototype (under construction)
TOSHIBA
Satellite

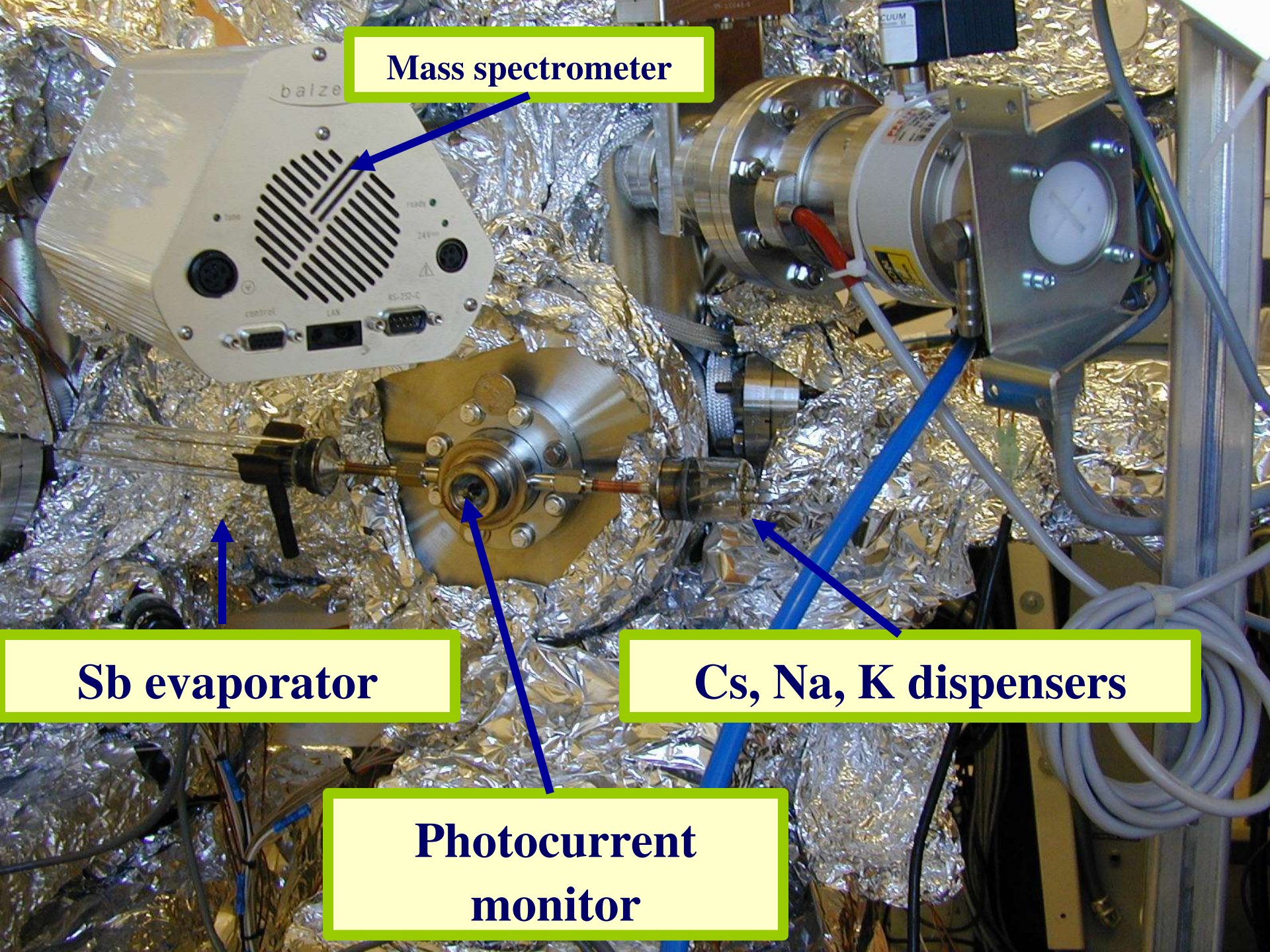
7-pixel 5-inch ReFerence Flat-Panel Prototype

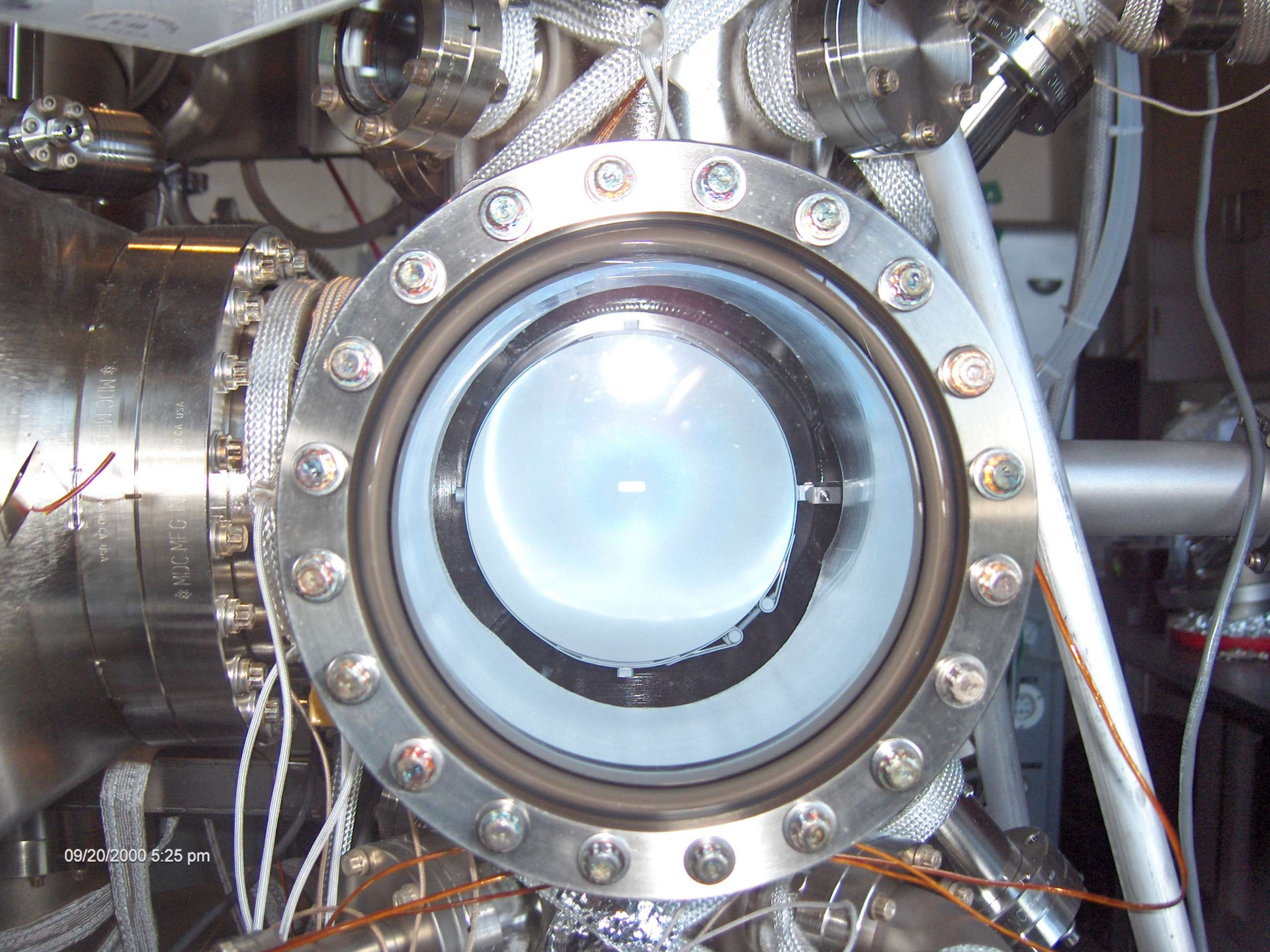




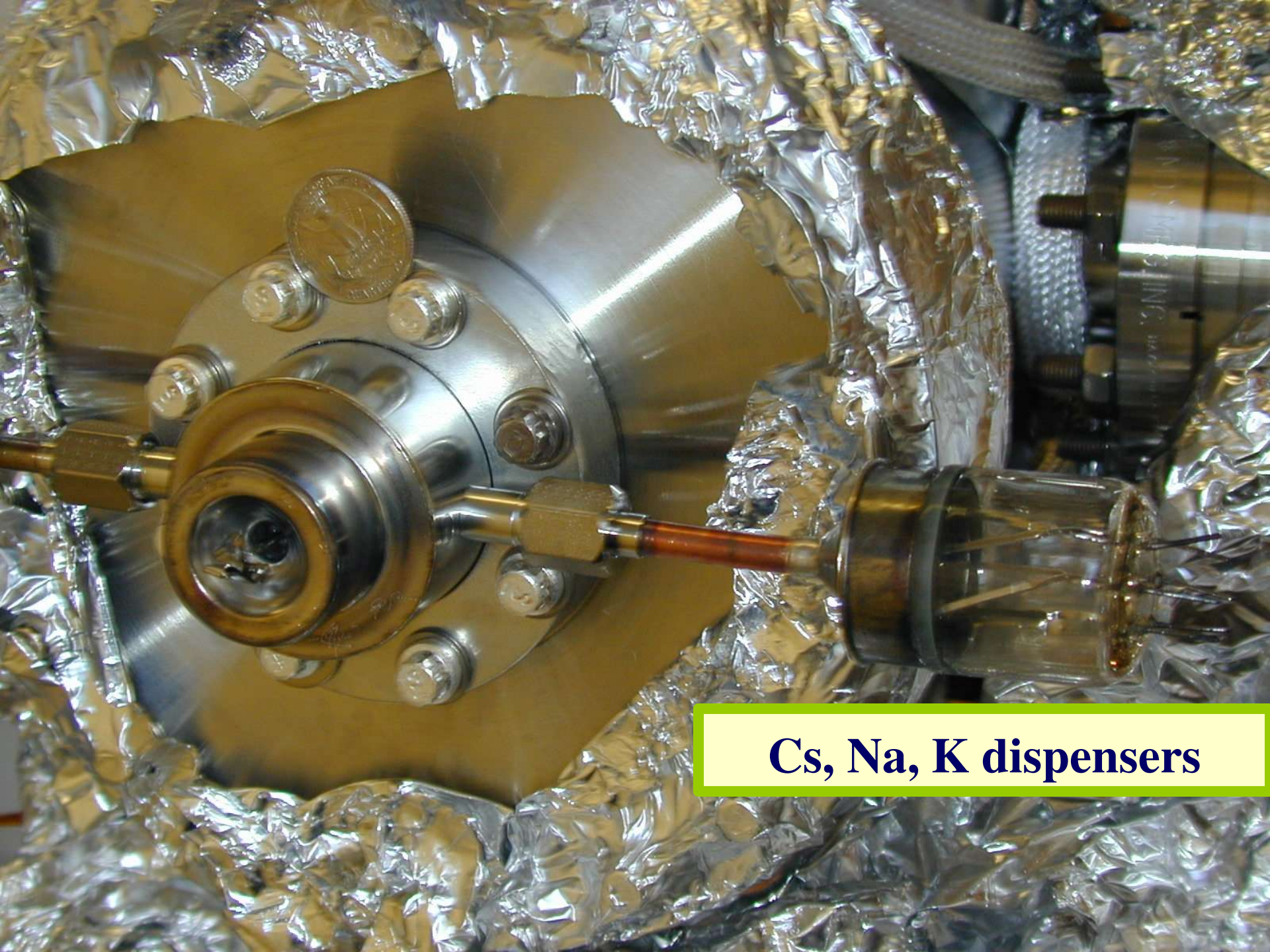
UHV Transfer System :

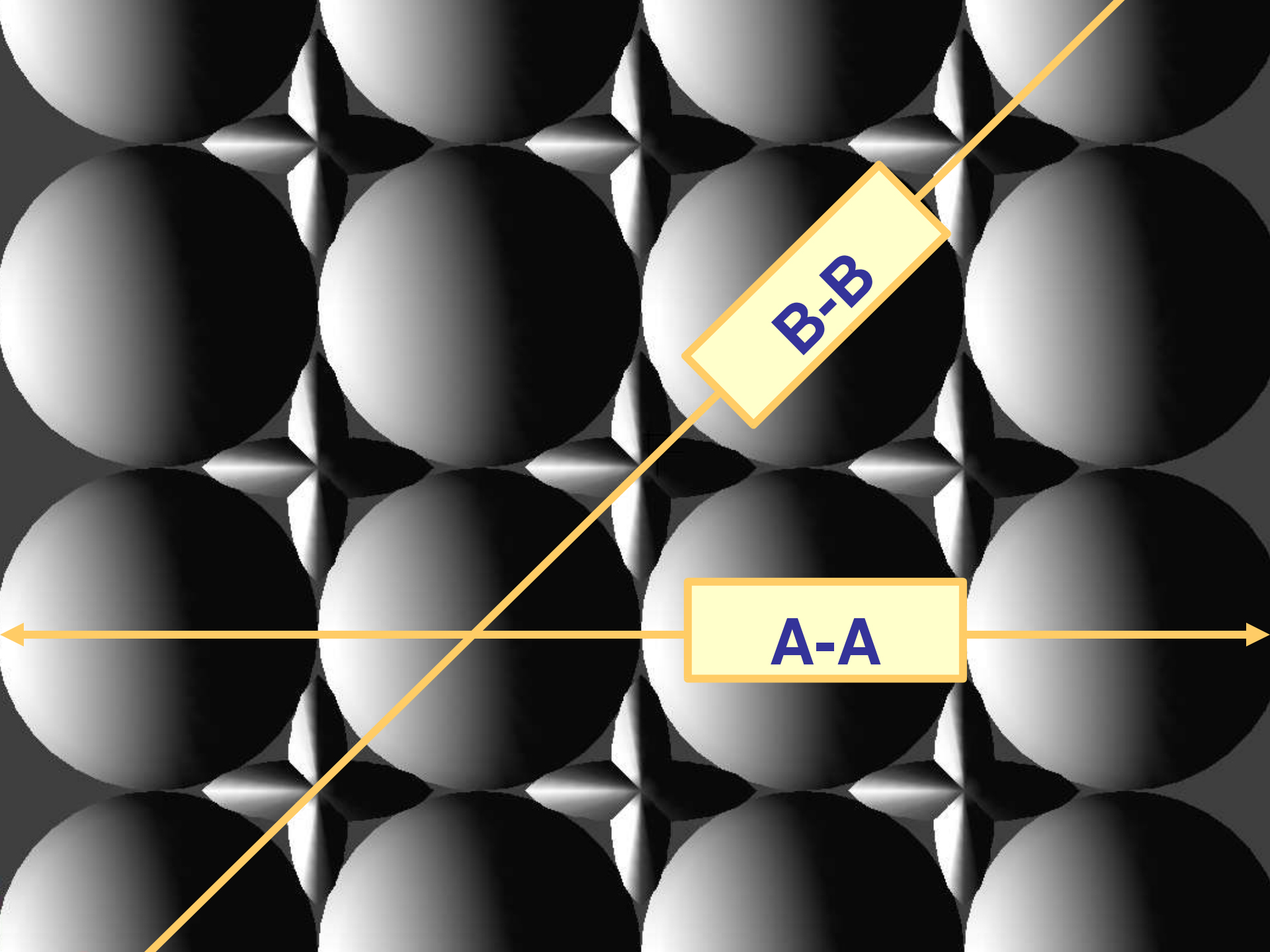
- **Photocathode deposition**
- **Indium/Au/Cr deposition**
- **Vacuum sealing**

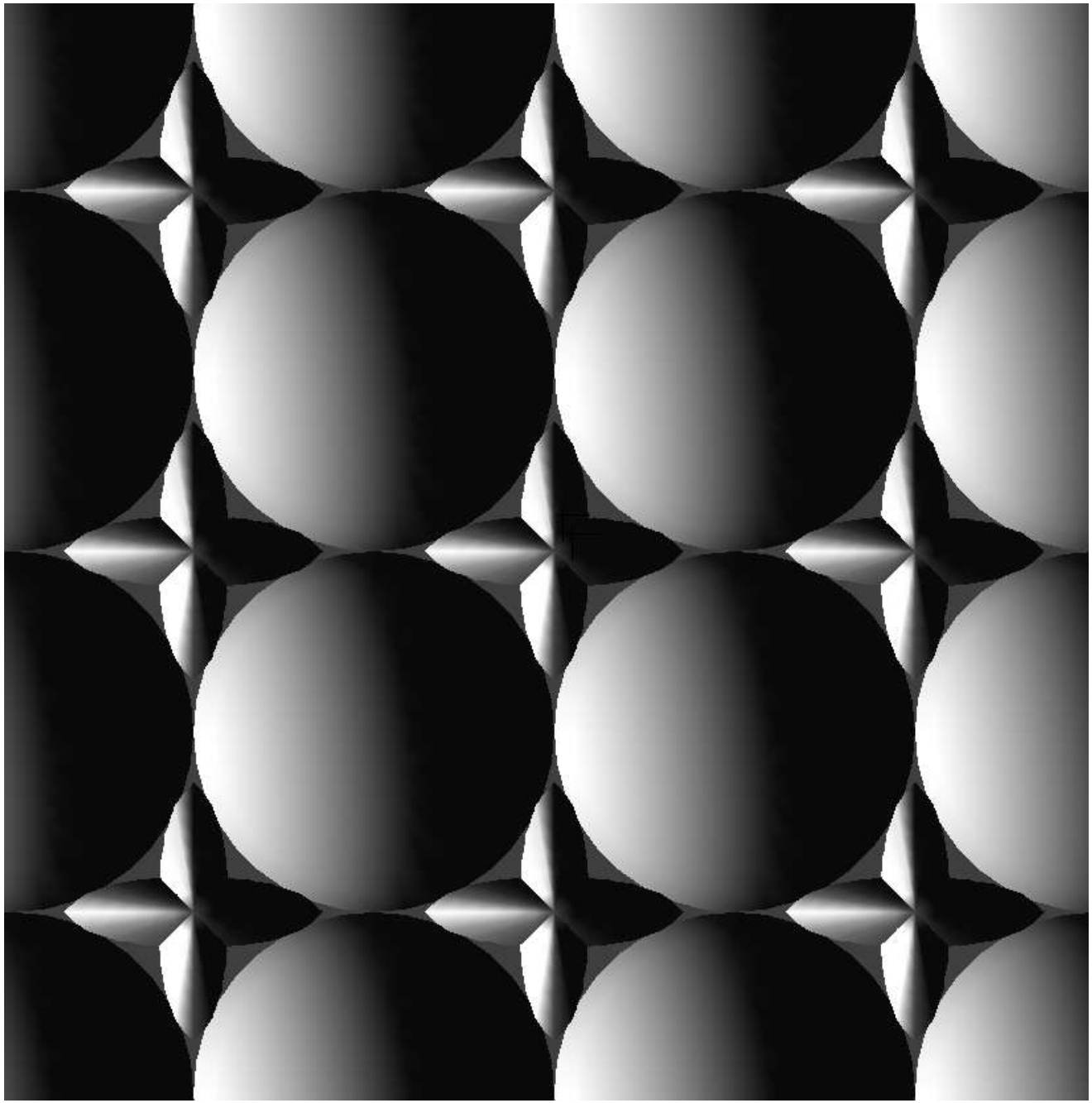

Mass spectrometer
Sb evaporator
Cs, Na, K dispensers
Photocurrent monitor

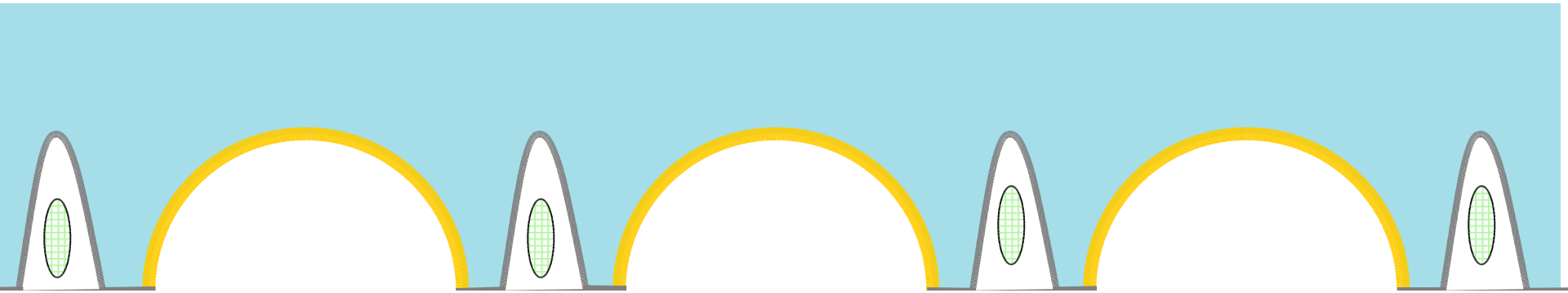

09/20/2000 5:25 pm

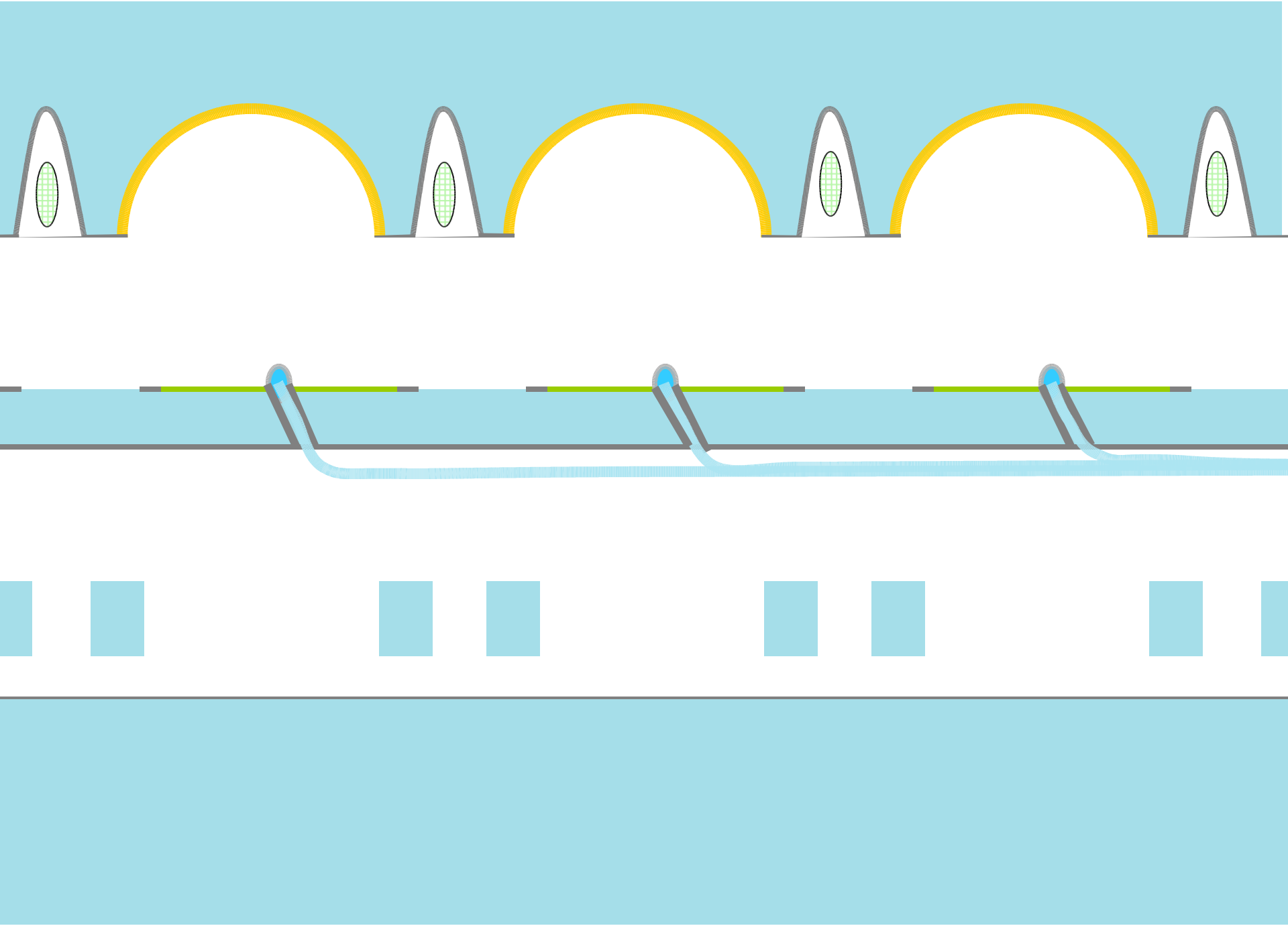

RCA

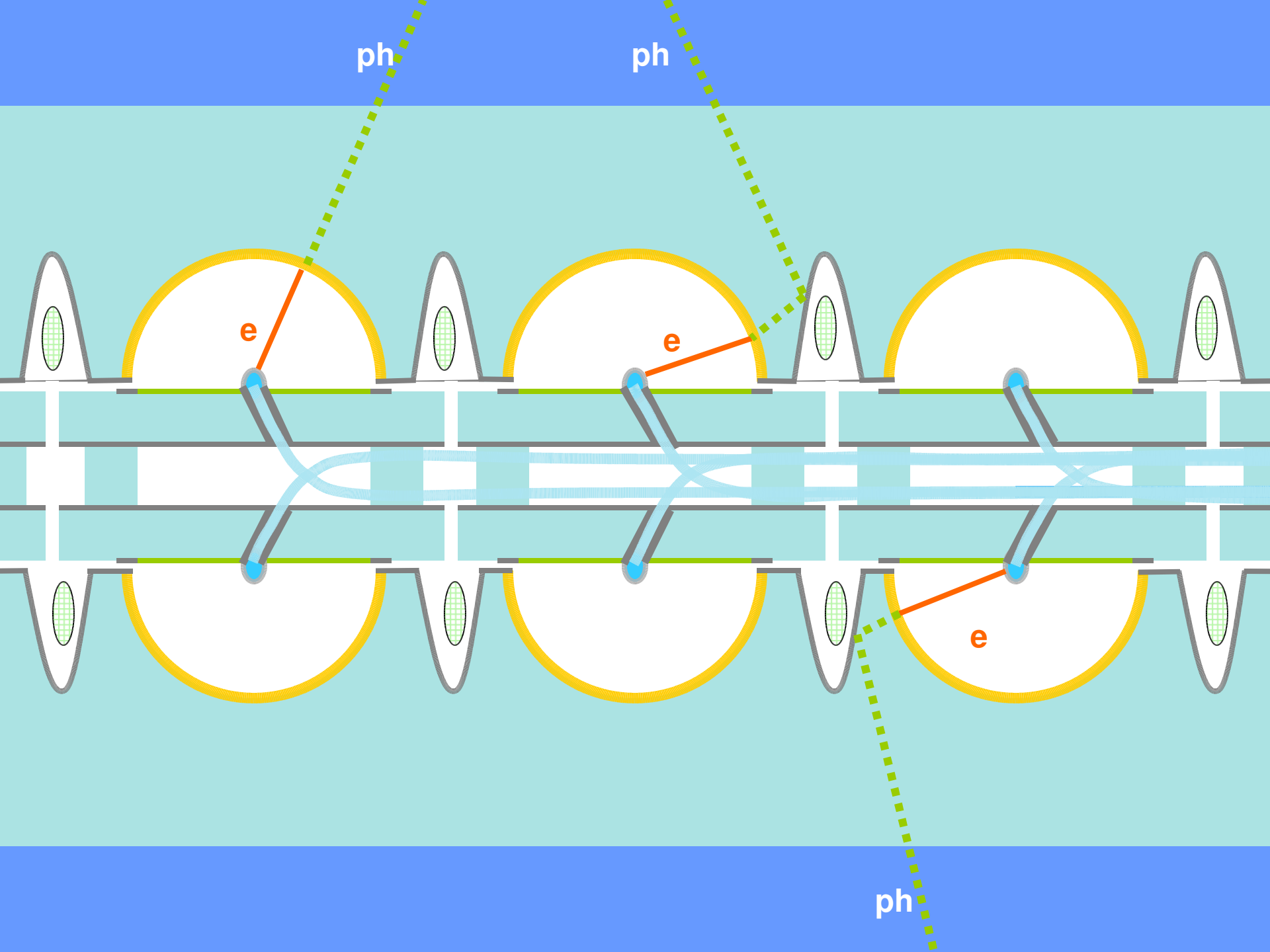

Cs, Na, K dispensers


B-B
A-A





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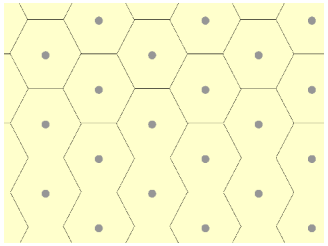
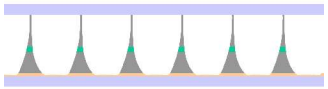
Advanced Photosensors

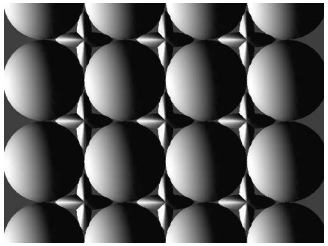
ULTIMATE: FLAT-PANEL

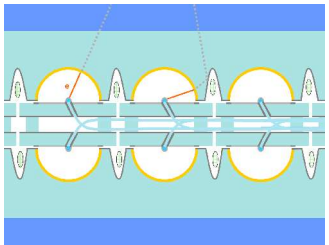
ReFerence



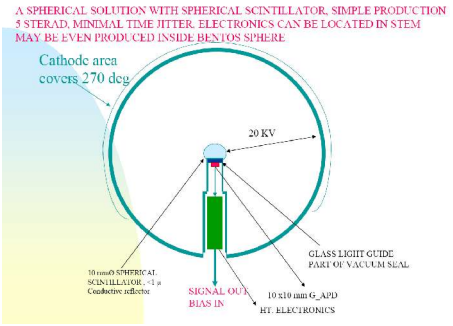


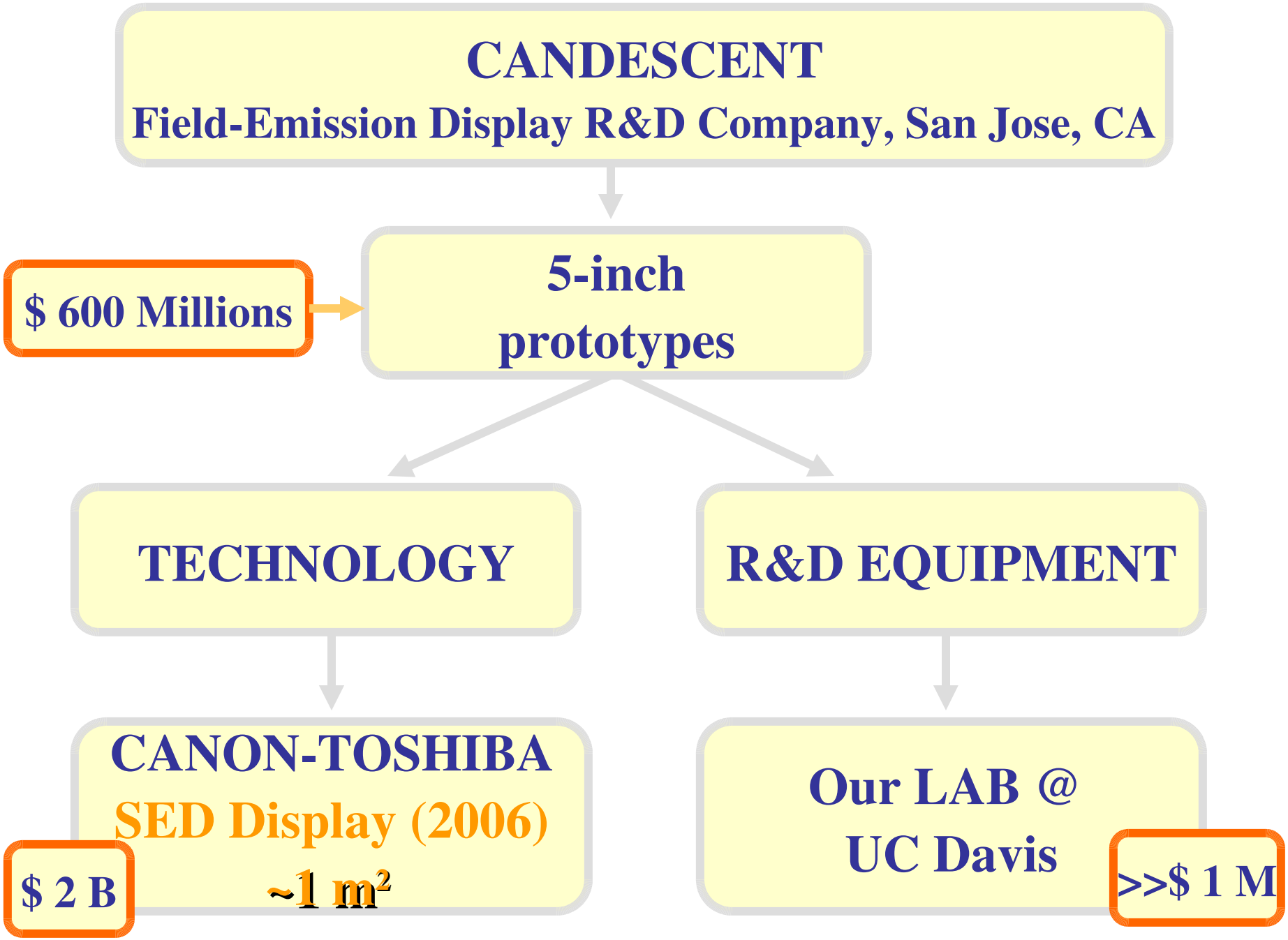
ArcaLux





INTERMEDIATE: HEMISPHERICAL Light Amplifier




CANDESCENT
Field-Emission Display R&D Company, San Jose, CA
$ 600 Millions
5-inch
prototypes
TECHNOLOGY
R&D EQUIPMENT
CANON-TOSHIBA
SED Display (2006)
~1 m2
$ 2 B
Our LAB @
UC Davis
>>$ 1 M

1. Dielectric

2. Patterned Resister Layer

3. Cathode Glass

4. Row Metal

5. Emitter Array

6. Single Emitter Cone & Gate Hole

7. Column Metal

8. Focusing Grid

9. Wall

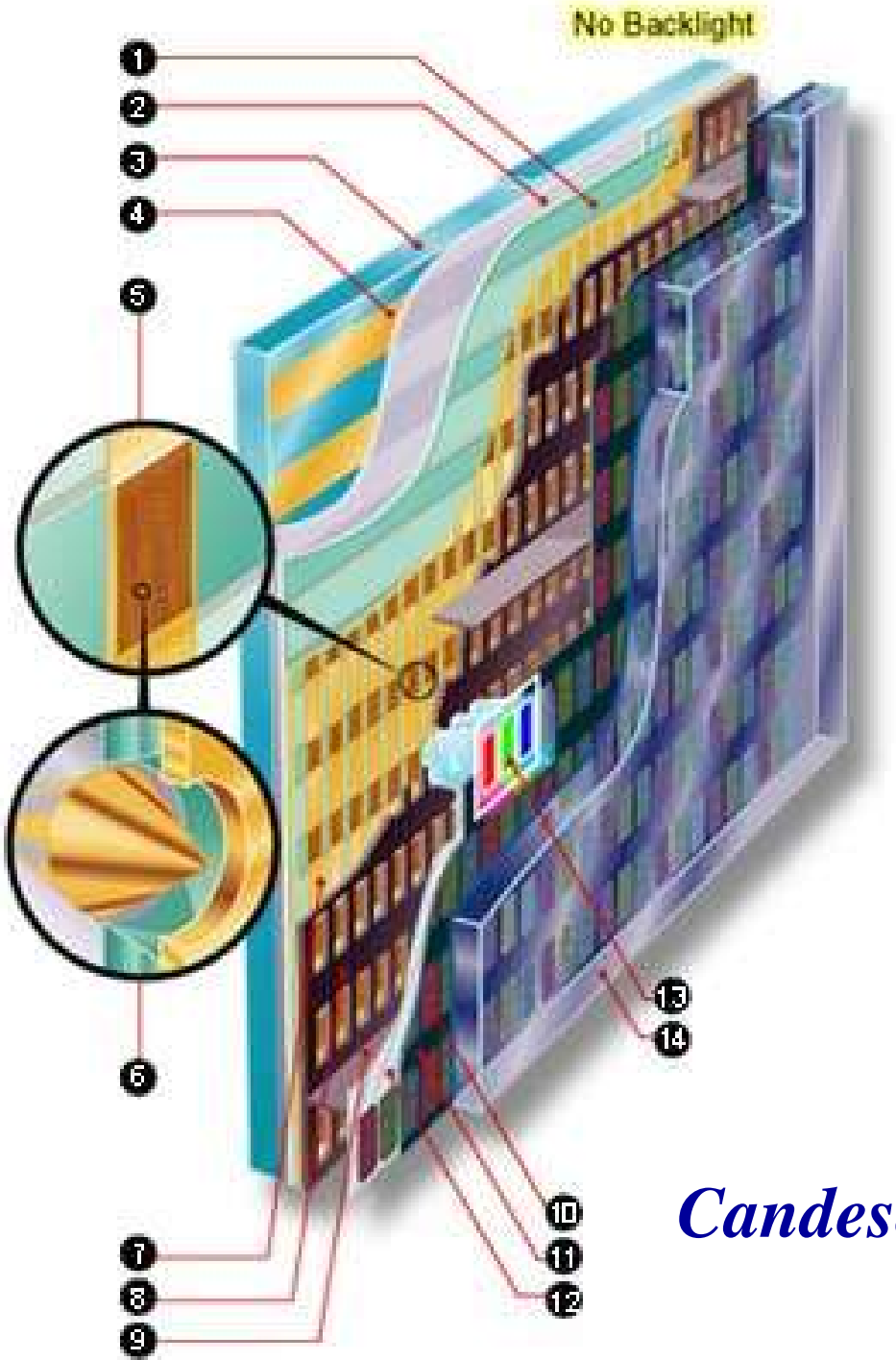
10. Phosphor

11. Black Matrix

12. Aluminum Layer

13. Pixel On

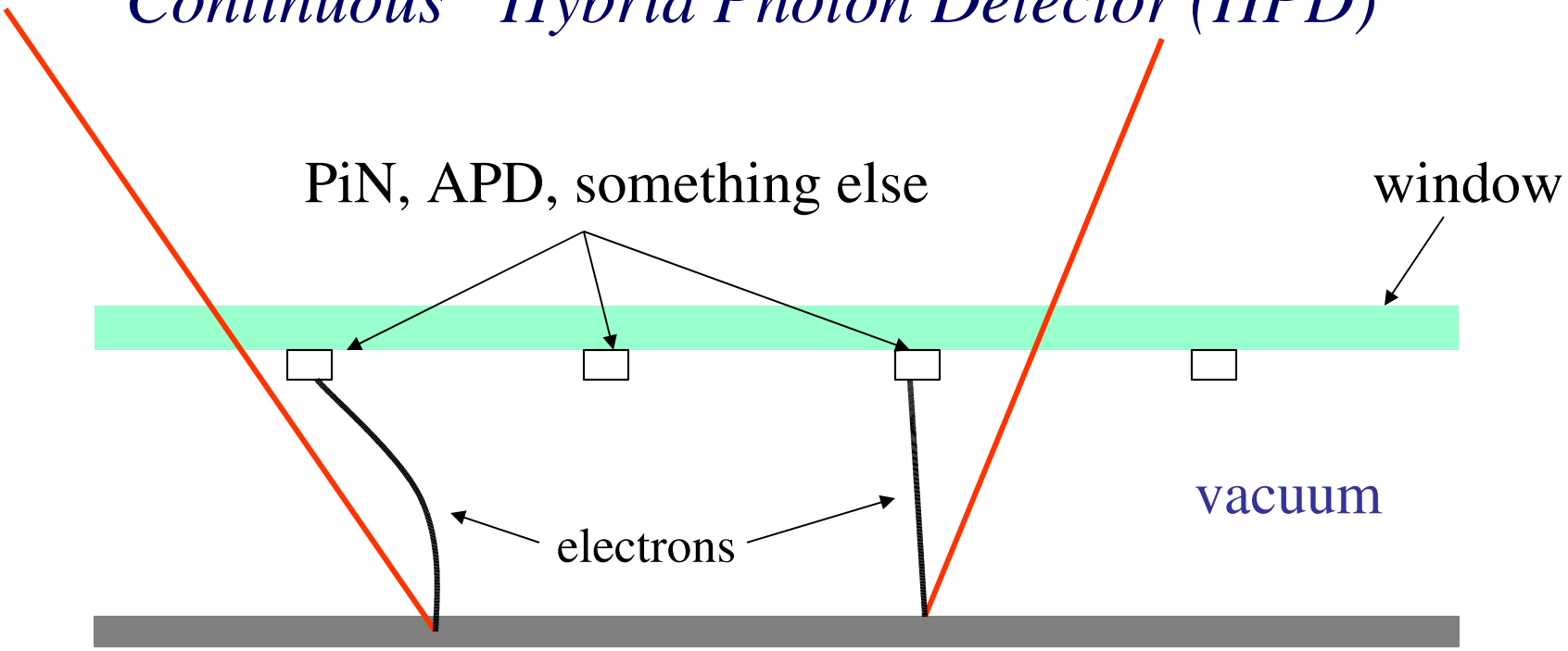
14. Faceplate Glass



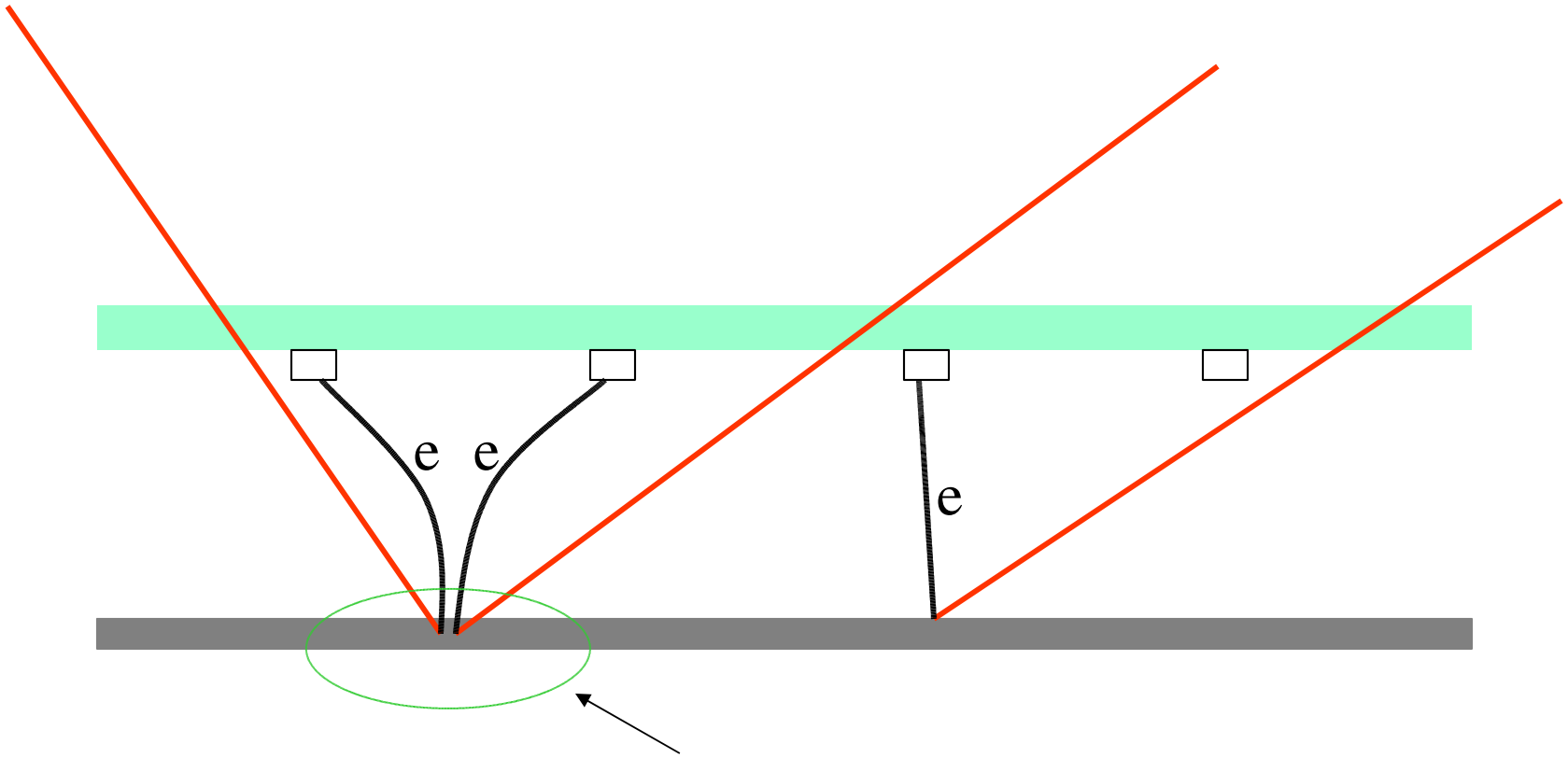
Candescent

Flat Panel Camera – wishful thinking:

"Continuous" Hybrid Photon Detector (HPD)



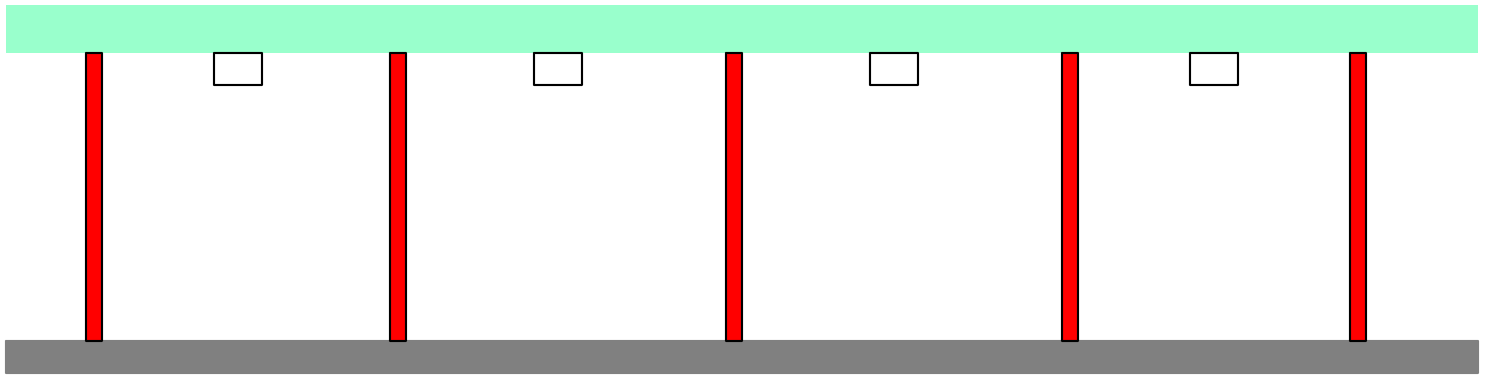
Problem #1 – Electron Optics



This doesn't work!

Problem #2 – Mechanical Stability

(flat plates need supports)



Flat-Panel Pixelized Camera Configuration→

provided by the *ReFerence* Photosensor Concept