Development of a 10-inch HPD with Integrated Readout Electronics

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1. CLUE – an air shower Cherenkov experiment
2. The 5-inch Pad HPD
3. Development of a 10-inch HPD
4. Rb₂Te photocathode
5. Self triggering readout electronics
CLUE = Cherenkov Light Ultraviolet Experiment

Imaging Air Cerenkov Telescope with 9 detector units

Single unit
- F/1 Parabolic Mirror, 1.8 m Ø
- UV Detector in focal plane

\[ N_{pe} \sim \int QE \cdot T_{quartz} \cdot T_{O2} \cdot dE \]
1 step back: The 5-inch Pad HPD

- Bialkali $K_2CsSb$ cathode on UV extended borosilicate window (schott 8337)
- 114 mm active diameter
- Si sensor, 2048 channels, $1 \times 1 \text{ mm}^2$
- Integrated readout electronics (IDEAS VA2, VA-prime)
- Nominal operational voltage: 20 kV
- Fountain focusing optics
  - $D \sim 2.4$
  - $\rightarrow$ segmentation on cathode
  - $2.4 \times 2.4 \text{ mm}^2$
- Originally developed for LHCb RICH detectors
- Since January 2000 continued as independent R&D project
Radial dependence of the quantum efficiency of HPD PC68 for $\lambda=230$, 290 and 350 nm. Non-uniformity ($\pm 10\%$) mainly due to reflections from Si and electrodes.

Peak QE in the range $25\pm 3\%$ is routinely reached!
Simon SIMION 7.0

20 kV, $\cos(\theta)$, 1.5 eV

Linear demagnification
$D = 2.60$

Cut pedestal noise at $n_\sigma = 4$

HPD 'proper' noise

Total noise

Electronics noise

Point spread function (on silicon) (mm)

Beaune 2002, C. Joram / CERN

Pedestal cut $n_\sigma$
HPD PC100

20 kV
VA' chip set
(350 ns shaping time)

<signal> = 23.13
\(\sigma = 2.74\)

\(E_0 = 1.5\) keV
LHCb beam test with aerogel radiator (May 2001)

Use Pad HPDs
PC84 / 85 / 86 / 87

See separate poster
(Tito Bellunato et al.)
The 10-inch HPD

Characteristics of the final version

- Rb$_2$Te cathode, 4-7 eV, “solar blind”
- Quartz or UV ext. borosilicate window
- Demagnification ca. 4
- Segmentation on cathode level ca. 4 x 4 mm$^2$
- Integrated self triggering electronics

- Envelope originally designed and fabricated for the AQUARICH prototype experiment (T. Ypsilantis et al.)
# HPD’s development and production at CERN

<table>
<thead>
<tr>
<th>Year</th>
<th>Model</th>
<th>Features</th>
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| 1998 – 2001 | HPD 5” | - Optimised for RICH applications (LHCb)  
- K$_2$CsSb photocathode  
- UV extended window  
- 2048 readout pads |
| 2001 - 2003 | HPD 10” | - Optimised for Cherenkov based air shower detectors  
- UV extended (or quartz) window  
- Rb$_2$Te photocathode |
Electron optical simulations
(SIMION 7.0)

U = -20 / -19.6 / -16. / -13.5 / -7 kV
Electron optical simulations (cont’d)

Linear demagnification up to R=120 mm

Electron distribution on silicon for point source at $x_{\text{cathode}} = y_{\text{cathode}} = 0$

- $<E_{\text{kin}}> = 1.5$ eV, $\cos(\theta)$ distributed emission
- $U_{\text{cathode}} = -20$ kV
- RMS $= 1.3$ mm
The Rb$_2$Te photocathode

Rb$_2$Te has similar characteristics than the well known ‘solar blind’ Cs$_2$Te cathode.

However, very important for our application: the response of Rb$_2$Te above 300 nm is ~10-100 times lower.

Resistivity of cathode is very high: $> 10^{10}$ O/$\Omega$
Conductive under-coating required to allow for reasonable photocurrents and uniform cathode response.
Indium Tin Oxide (ITO) ⇔ Chromium as transparent conductive layers

Our standard layer:
- ITO film thickness : 3.2nm
- Vacuum evaporated + post oxidation in air at 300ºC for 8 hours
The $\text{Rb}_2\text{Te}$ co-evaporation process

- Excellent vacuum after bake-out
  (160°C, tube at 300°C)
  $p \sim 5 \times 10^{-9}$ mbar
  $p_{\text{H}_2\text{O}} \sim 1 \times 10^{-9}$ mbar

- Tank + substrate at $T \sim 70^\circ$C

- Permanent monitoring of
  $I_{\text{photo}}$, all other essential
  parameters
  ($p$, $T$, $I_{\text{source}}$)

- Start with
  evaporation of Rb only
  $\rightarrow I_{\text{photo}} \sim$ few pA

- Co-evaporate Rb and Te

- Stop when Q.E. (250 nm)
  reaches maximum
The HPD development plant

- Coat substrates up to $\phi$ 10”
- Adapted to UV–VIS PCs, from 200 to 800 nm
- Press mechanism for cold indium encapsulation (2.5 tons)
- Production capacity limited to ~ 1.5 HPD / week
Two HPDs produced

HPD PC99

Extrapolation to quartz window

Direct measurement

HPD PC101

QE (%), extrapolated to quartz window

Ref. Hamamatsu
Side discovery: Under-layer has strong influence on cathode growth.

Photocathode PC96

- Hemisphere with ITO
- Hemisphere without ITO

Half of HPD window coated with ITO (3 nm)

ITO no ITO

2 bialkali photocathodes with ITO
2 bialkali photocathode without ITO

ITO seems not work for K₂CsSb cathodes!
Set-up for holding and heating the 10” envelope during evaporation

All components machined in Pisa, most of them now finished.
Electronics: IDEAS VaTagp3 - a self triggering analogue chip

Existing chip:

\[ \tau_{\text{slow peak}} = 3 \, \mu s \]
\[ \tau_{\text{fast peak}} = 150 \, \text{ns} \]

noise \~ 350 \, \text{e}^- \, (\text{ENC})

Faster chip under design

\[ \tau_{\text{slow peak}} = 1 \, \mu s, \]
\[ \tau_{\text{fast peak}} = 35 \, \text{ns} \]

Sparse readout scheme allows readout rates > 100 kHz.
Summary and outlook

The 5-inch Pad HPD works up to specifications. Development practically finished.

The ingredients for the fabrication of a 10-inch solar-blind HPD are being developed

- Co-evaporation process \(\rightarrow\) Excellent \(\text{Rb}_2\text{Te} \) (ITO) photocathodes
- Two 5” HPD with \(\text{Rb2Te} \) cathodes (borosilicate window) produced and characterized
- Electron-optics of 10” tube studied
- Most of the mechanical components for the evaporation plant available

Time plan

- Still in 2002: First 10” HPD with bialkali cathode on glass window, VA-prime electronics
- Summer 2003: First 10” HPD with \(\text{Rb}_2\text{Te} \) cathode on quartz window, VaTagp electronics

In our spare time we dream of another nice gadget…
Development of a proximity focused HPD

- Optimized for medical applications
- $K_2CsSb$ photocathode
- Flat Sapphire window
- Ceramic rectangular body
- Very high active area fraction