The TORCH PMT:
A close packing, multi-anode, long life MCP-PMT for Cherenkov applications
Contents

- TORCH Background/Detector Requirements
- ALD Gain/Uniformity results
- Hybrid multi-anode charge sharing Anode Simulation
- Electronics Coupling - Anisotropic Conductive Film
- 2” Square MCP detector
THE TORCH PROJECT
TORCH - Motivation

• The Timing Of internally Reflected Cherenkov light (TORCH) is an ERC funded R&D project

• Proposal to upgrade LHCb Particle ID capabilities in 2-10 GeV/c region
TORCH – TOF Concept

• TORCH aims to achieve 10-15ps timing per particle over a large area
• Utilises Cherenkov light for fast signal production
• Cherenkov light transported to photon detectors via total internal reflection
• Focussing optics along edges converts Cherenkov angle to position on focal plane
Photon Detector - Spatial

- Photon propagation angle converted into position on focal plane
- Produces “smile” corresponding to the Cherenkov ring
  - One axis has long arm → coarse spatial resolution
  - One axis has short arm → fine spatial resolution
- For 2” square tube, and 1 mrad angle resolution
  - 128 pixels for fine axis, 0.41 mm pitch
  - 8 pixels for coarse axis, 6.63 mm pitch

\[ L = \frac{h}{\cos \theta} \]
Photon Detector - Spatial

• We plan to use a hybrid charge sharing/multi-anode design
  – Reduces number of required channels
  – Well defined charge footprint
  – No vacuum feed-throughs

• The 36 MHz/cm² TORCH rate limits degree of charge sharing due to occupancy issues (no more than 3 pads at once)
Photon Detector - Timing

- Pion-Kaon time-of-flight difference ~35ps over 9.5m
  - 3σ separation requires 10-15 ps timing per particle
  - Each particle produces ~30 detected photons
- Hence need 50ps timing from detector/electronics combined

Photon Detector - Lifetime

• Over 5 years of operation expected cumulative charge extracted from MCP is 5 C/cm$^2$
• Required new technology to extend lifetime of MCP detector from <0.1 C/cm$^2$ (due to photocathode damage)
Photon Detector - Lifetime

- Using Atomic Layer Deposition to deposit $\text{Al}_2\text{O}_3$
  - prevents ion feedback (seals MCP surface)
  - improves MCP gain (higher Secondary Electron Yield)
For further TORCH details see
M.W.U van Dijk et al., TORCH - a Cherenkov based
time-of-flight detector, DOI: 10.1016/j.nima.2014.04.083
CHARGE SHARING ANODE
Photon Detectors

- Micro Channel Plate PMT
- Anode pad structure equivalent to 8x128 pixels
- Using NINO ASIC a time-over-threshold amplifier/discriminator with HPTDC time to digital converter

Schematic layout of MCP-PMT. Charge footprint shown enlarged.
Charge Sharing Simulation

• Performance of charge sharing heavily reliant on detector/electronics parameters
  – Exact geometric structure of charge sharing anode
  – Size of charge cloud footprint from MCP
  – Detector Gain
  – Electronics Threshold/Noise

• Due to occupancy issues have 8×64 physical readout anodes to provide a 8×128 pixel resolution detector
Charge Sharing Simulation

• Monte Carlo model developed which simulates
  – Current pulse output from MCP
  – Detector gain distribution, including mean charge footprint size
  – Charge sharing anode design parameters
  – Response of NINO time-over-threshold discriminator (noise, charge measurement non-linearity)
  – TDC digitisation resolution
Charge Sharing Simulation

- For each simulated photon determine position error

  ![Simulated photon $x$ position error](chart.png)

  - Physical Pad Size = 0.83 mm
  - Virtual Pixel Size = 0.41 mm

- RMS of photon error distribution is the key parameter
  - $< 0.21$ mm for $2\sigma$ reconstruction of 128 pixels
Charge Simulation

• Strongly depends on MCP gain and NINO threshold
• Require $\sim 10^6$ gain
• Per photon event mean number of pads above threshold is 1.8 to 2.5
Charge Sharing Prototypes

• First prototypes due this week
  – Equivalent to a quarter of the final 2” square tube in circular envelope
  – 32×32 array of readout pads
  – In one dimension 8 pads connected for 4×32 readout in TORCH application
ELECTRONICS INTERFACE
ACF FILM
Electronics Interface

- High density multi-anode output requires space efficient connection to readout electronics
- Anisotropic Conductive Film (ACF) is the current chosen solution
- Thin Si polymer film, with embedded wires
- 100 µm wire pitch
Electronics Interface

- Sandwich ACF film between detector and readout PCB
- Minimum 10 contacts per pad
  - 0.1mm² contact area required
- Requires 100 MPa pressure applied to rear of detector
ACF Tests - IRPICS

- Using IRPICs detector as test bench
  - 32x32 multi-anode MCP detector
  - 0.8 mm pitch
  - 0.2 mm² contact pads
- Tested ACF readout using LeCroy scope (5 GHz, 20 GS/s)
ACF Tests – IRPICS + NINO
(Preliminary Results)

- Tested NINO readout using scope to measure NINO output
- No amplitude walk correction!
SQUARE DETECTOR DEVELOPMENTS
Square Detector

• Producing square, tightly packed MCP detectors have a number of challenges
  – Uneven stresses on detector body
  – Maximising active area required thin walls
  – Changes to sealing photocathode compared to a round detector body

• Experimented with
  – Wall thickness
  – Ceramic to ceramic seal for anode
  – Different Indium alloys for photocathode seal
Sealing Square Test Cells

• Successfully produced 2” square test cells, with 1mm thick wall and LNS20 photocathode

• QE stable over 4 month period
Conclusion

• Novel anode design combining parallel multi-anode readout with improved resolution using charge sharing information simulated, with prototype results soon

• Proved viability of ACF film for high density interconnects on MCP detectors

• Produced 2” square test cells with stable photocathodes
Future Work

• Test prototype detectors
  – Characterisation of anode design at Photek
  – Test TORCH concept with small scale quartz plate and MCP detector prototypes at test beam
• Build fully functioning 2” square detector
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