Photodetectors for High-B Fields

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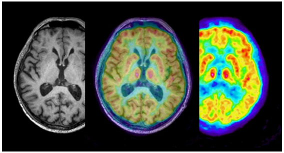
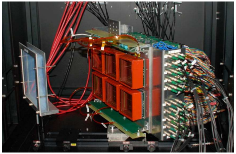
Outline

Objectives & Motivation

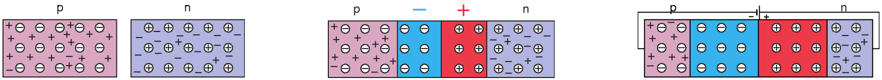
1. Testing of novel position sensitive single photon detectors for operation in high magnetic fields
   - Silicon Photomultipliers (SiPM): B field insensitive, ideal for MRI+PET combination
   - Microchannel Plate Photomultiplier Tube (MCP-PMT): B field resistant, ideal for use in a RICH counter
   - Hybrid Avalanch Photodiode (HAPD): B field resistant, ideal for use in a RICH counter
2. Perform basic detector characterisations
   - SiPM: Temperature dependences, geometrical efficiency, energy & Timing resolution,
   - MCP-PMT: Quantum efficiency v.s. wavelength, Afterpulsing behaviour
3. Develop and test prototype devices
   - SiPM TOF-PET Module with Depth of Interaction encoding (Ph.D. topic)
   - Aerogel Ring Imaging Cherenkov with MCP-PMT: Beamtests @ KEK and CERN



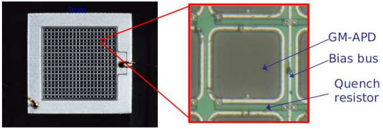
- PET + MRI → High B-field → ~~PMT~~
- Particle ID in HEP → 1.5T B-field (~~PMT~~) for momentum + velocity → mass → RICH counter



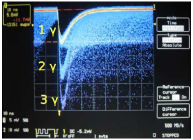
Silicon Photomultiplier (SiPM)

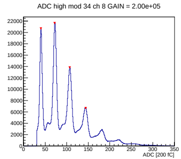


- Array of Avalanche Photo-Diodes (APD):
  - Geiger discharge → 1 photon/APD
  - Array of APD's → dynamic range of SiPM
  - NO position sensitivity!

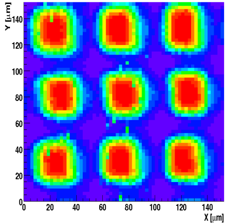


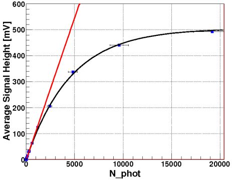
- Properties:
  - Low operation voltage ∼ 10-100 V
  - Gain ∼ 10^6
  - peak Photon Detection Efficiency (PDE) up to 35% (400 nm)
  - Time resolution ≤ 100 ps
  - Works in magnetic field → MRI-PET
  - Dark counts (DCR) are ≈ 100 kHz/mm^2 @ 1 p.e. level
  - DCR @ double photoelectron level → drops ≈ 10x

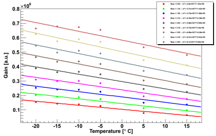




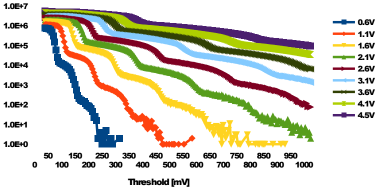
Basic Properties



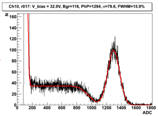


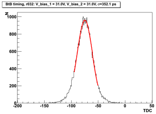


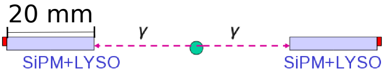
- Geometrical efficiency:
  - Positions scans: ≈ 33 % shown SiPM (STM prototype 50 μm pitch → fill factor = 36%)
- Linearity of response:
  - SiPM μcell detects a photon then needs to recharge → cell deadtime
  - cell deadtime → non-linear behaviour when nr. photons approaches nr. cells (4900 cells). LYSO scintillation pulse has ≈ 2000 photons detected
- SiPM gain vs temperature (-20°C → 15°C):
- SiPM DCR vs Applied BIAS:
  - Single photons DCR ≈ several MHz
  - 2 or more photons DCR rappidly drops to levels ≈ 100kHz and lower



Basic TOF-PET SiPM Performance







Temperature dependence:

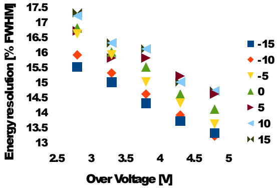
- Energy Resolution
- BtB Timing Resolution

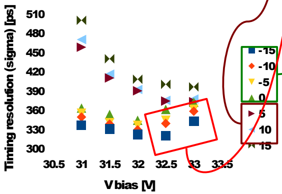
· Threshold ~ 150mV
· At higher V_{bias} noise triggers too much and degrades time res.

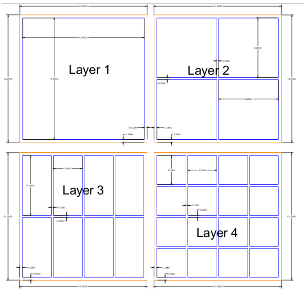
Threshold ~300mV

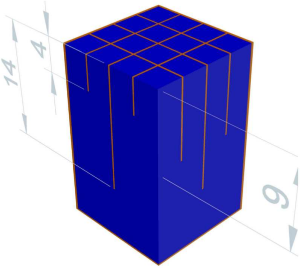
~ 13 - 17%

~ 320 ps



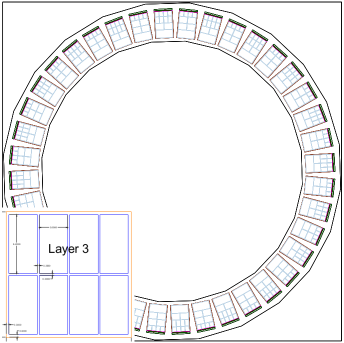


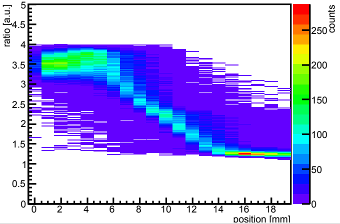




- Idea: Through DOI and light sharing, reconstruct the 3D interaction point of gamma's in the scintillator
- Increasing segmentation along depth of the crystal
- Segmentation chosen so it can be manufactured out of 1 block
- Light sharing determines depth of interaction (See table for rough sharing)
- Ratios between the channel readouts → depth

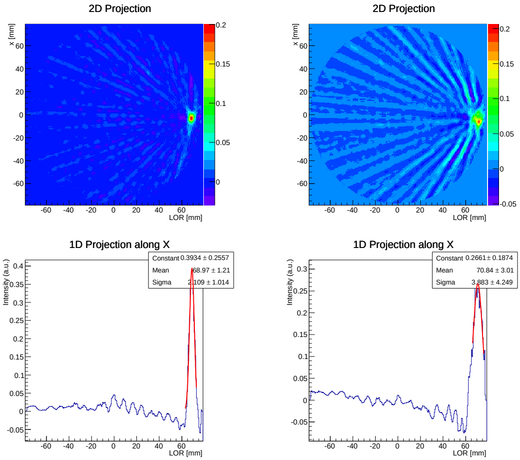
Layer	$\frac{Q_{max}}{Q_{min}}$	$\frac{SQ_{max}}{SQ_{min}}$	$\frac{CH_{max}}{CH_{min}}$
1	1	1	1
2	5	5	5
3	5	9	9
4	5	9	17



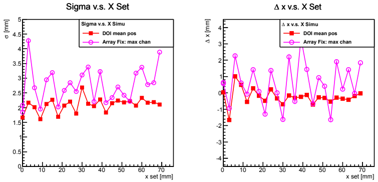


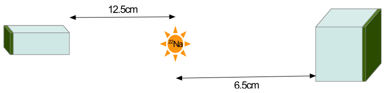
- Full ring was simulated (GEANT4) with segmented crystal and a crystal array
- Ring radius is 100 *mm*
- Point source is moved in steps of 3 *mm* along x-axis
- Center of the maximum channel or by calculating the mean position based on the light sharing over the channels → position in the plane of SiPM module
- The $\frac{Q_{max}}{CH_{max}}$ ratio → determine propability of interaction happening in a particular layer

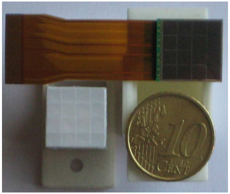
Exteme off-axis 69 mm



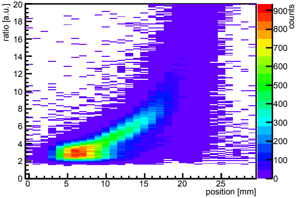
- STIR 2D filtered backprojection software package is used
- Left: segmented crystal
  - Reconstructed source position at ≈ 69 mm
  - Sigma = 2.1 mm
  - Good source position with a fairly narrow and stable error margin.
- Right: Crystal array
  - Reconstructed source position at ≈ 70.8 mm
  - Sigma = 3.9 mm
  - poor position and error margin gradually degrades
- Zig-zag near center most likely due to gaps between modules (still under investigation)

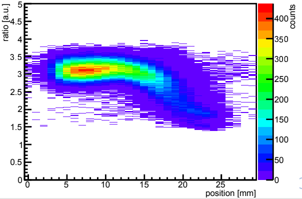


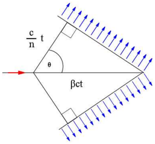




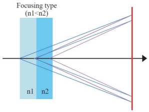
- SiPM module = Hamamatsu S11830-3344MT 4x4 SiPM in monolithic package
- LYSO from Sinocera
- Rough ratios follow the pre-calculated ratios
- The $\frac{Q_{max}}{Ch_{max}}$ ratio show the same pattern as found in the simulations, but show an expected broadening due to the acceptance angle of the single SiPM trigger.

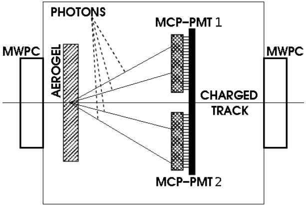


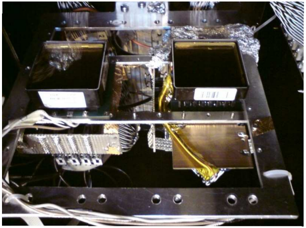


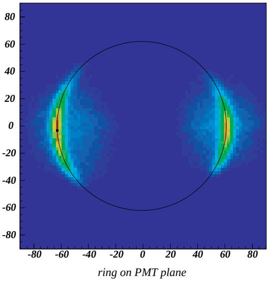


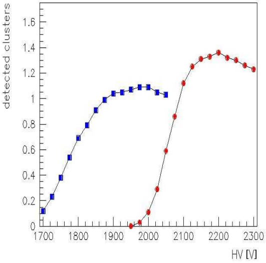
- Charged particles passing trough matter $v > c$:
  - prompt Cherenkov photons
  - Threshold energy $\rightarrow \sqrt{\frac{2E_{Thr}}{m}} = v_{Thr} > c/n$
- Aerogel RICH:
  - Light material → minimize particle interaction
  - Use of multiple layers with varying index of refraction → focusing effect
- ARICH counter using 2 Planacon MCP-PMT's (10 μm and 25 μm pores)



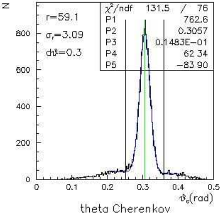


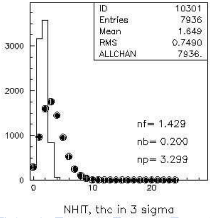




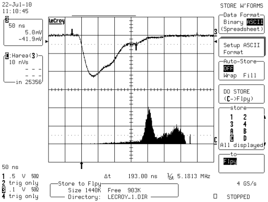


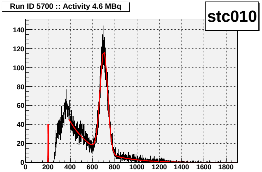
- 2 GeV/c Pion beam at KEK (Japan)
- MWPC used for tracking and Scintillator for timing
- 2 Aerogels used:
  - $n_1 = 1.048$, thickness $= 19.4\ mm$
  - $n_1 = 1.062$, thickness $= 20.2\ mm$
  - Focal lenght $\approx 165\ mm$
- HV scan $\rightarrow$ clusters in cherenkov ring reaches plateau around 2200V (10 μm) and 2000V (25 μm)
- Cherenkov angle $= 15\ mrad$, with ≈ 1.6 photons per track $\rightarrow \approx 8$ photons for full coverage



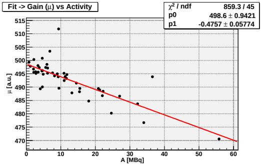


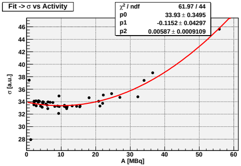
AX-PET at CERN: 15-30/07/2010

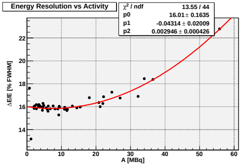




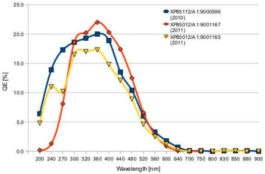
- Purpose and opportunities of the exchange
  - Obtain an impression of a fully functional PET prototype
  - Assist in the study of the prototype performance
  - Opportunity to interact with specialists in DAQ, machine study, PET reconstruction
- Energy resolution vs Phantom Activity rates:
  - Oscilloscope was used to measure energy spectra
  - No trigger available $\rightarrow$ disconnect signal $\rightarrow$ baseline
  - Gaussian fit for Photopeak and baseline $\rightarrow$ μ (Gain) and σ
  - $\Delta E = \frac{2.35 * \sigma}{\mu}$
- Up to $\approx 16.5\ MBq$, ΔE remains stable

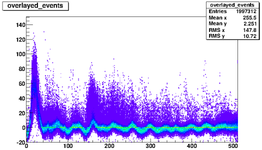


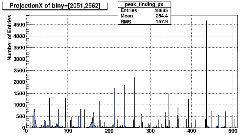




Photonis: 4-8/4/2011 + 18-22/4/2011







Quantum Efficiency

- Setup designed for image intensifiers
- Photocathode current with filter $\rightarrow$ QE at λ
- UV QE setup $\rightarrow$ manual and only for specific orders

MCP-PMT afterpulse behaviour

- Pulsed light source
- TARGET waveform sampler $\approx$ 100k waveforms
- Overlay all the waveforms $\rightarrow$ baseline $\rightarrow$ threshold
- ROOT TSpectrum $\rightarrow$ find peaks and count the ones above threshold

The Good

- Excellent training opportunity
- Getting a view into various HEP research centres
- Working together with THE experts

The not so good

- Industrial exchange
  - Could have been prepared better
  - Not necessary to spend 2 weeks
  - Could easily be done for a group
- Limited handson training

The Inevitable

- Finish my Ph.D.
- Find a job:
  - Unsure if industry or academia
  - Research / Engineering of HEP detectors
  - Strong focus on software development / systems integration