Application of WLS strips for position determination in PET tomograph based on plastic scintillators

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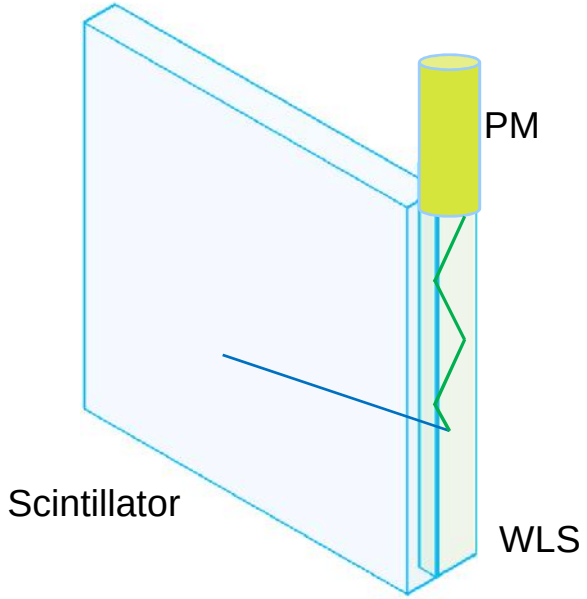
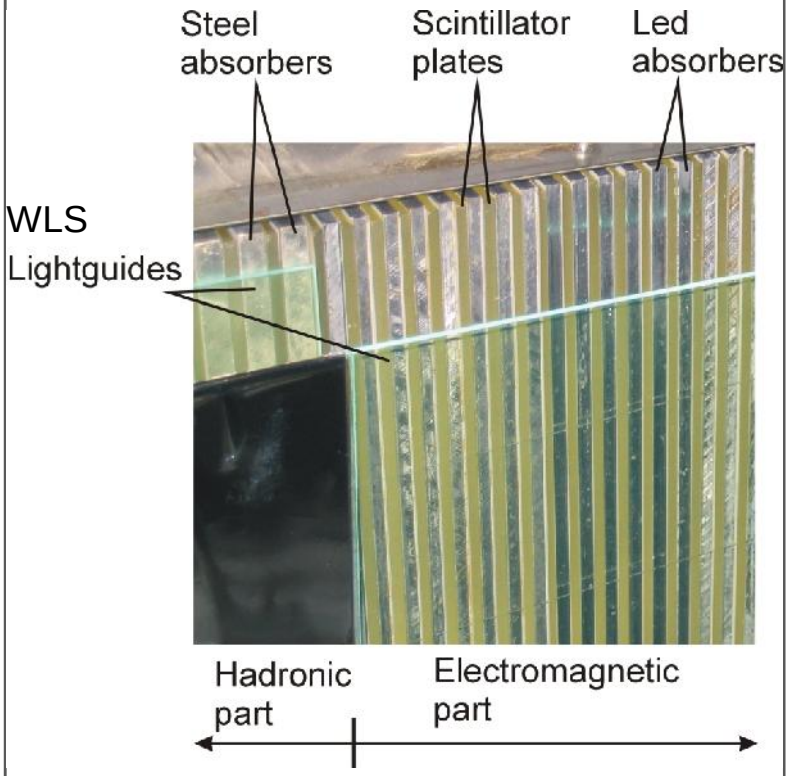
Wavelength Shifter (WLS)

WLS - a photofluorescent material that absorbs higher frequency photons and emits lower frequency photons (e.g. blue -> green), typically plastic on polyvinyltoluene base doped with aromatic molecules (dye)

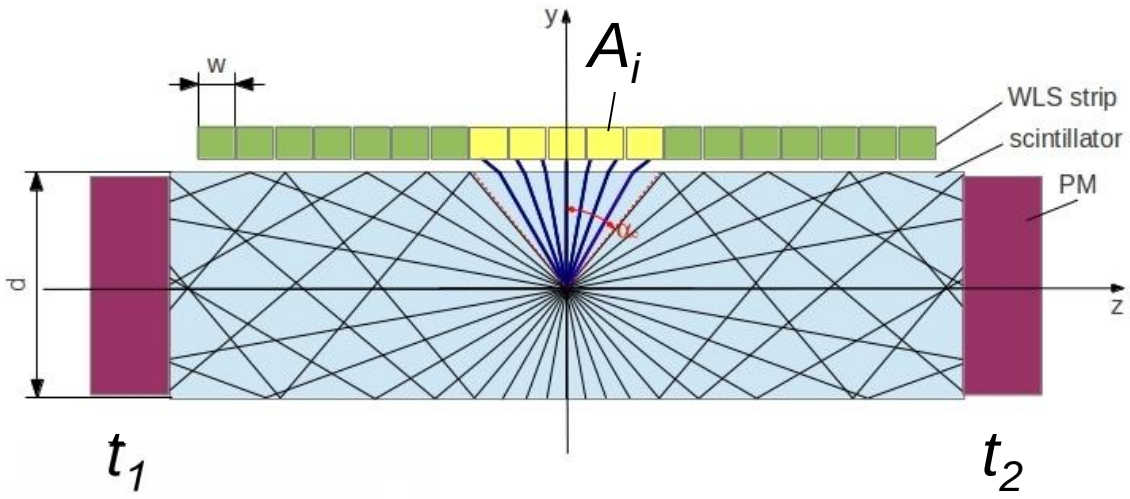
Can be used to collect scintillation light (large sensitive area, small readout area)



MIRAC calorimeter



Position determination in scintillator strip



Time of flight:

$$z = \frac{v}{2}(t_2 - t_1), \quad v \sim \frac{c}{2}$$

for $\Delta(t_2\text{-}t_1)$=100 ps (FWHM) Δz=7.5mm

WLS readout:

$$z = \frac{\sum_i A_i zi}{\sum_i A_i}$$

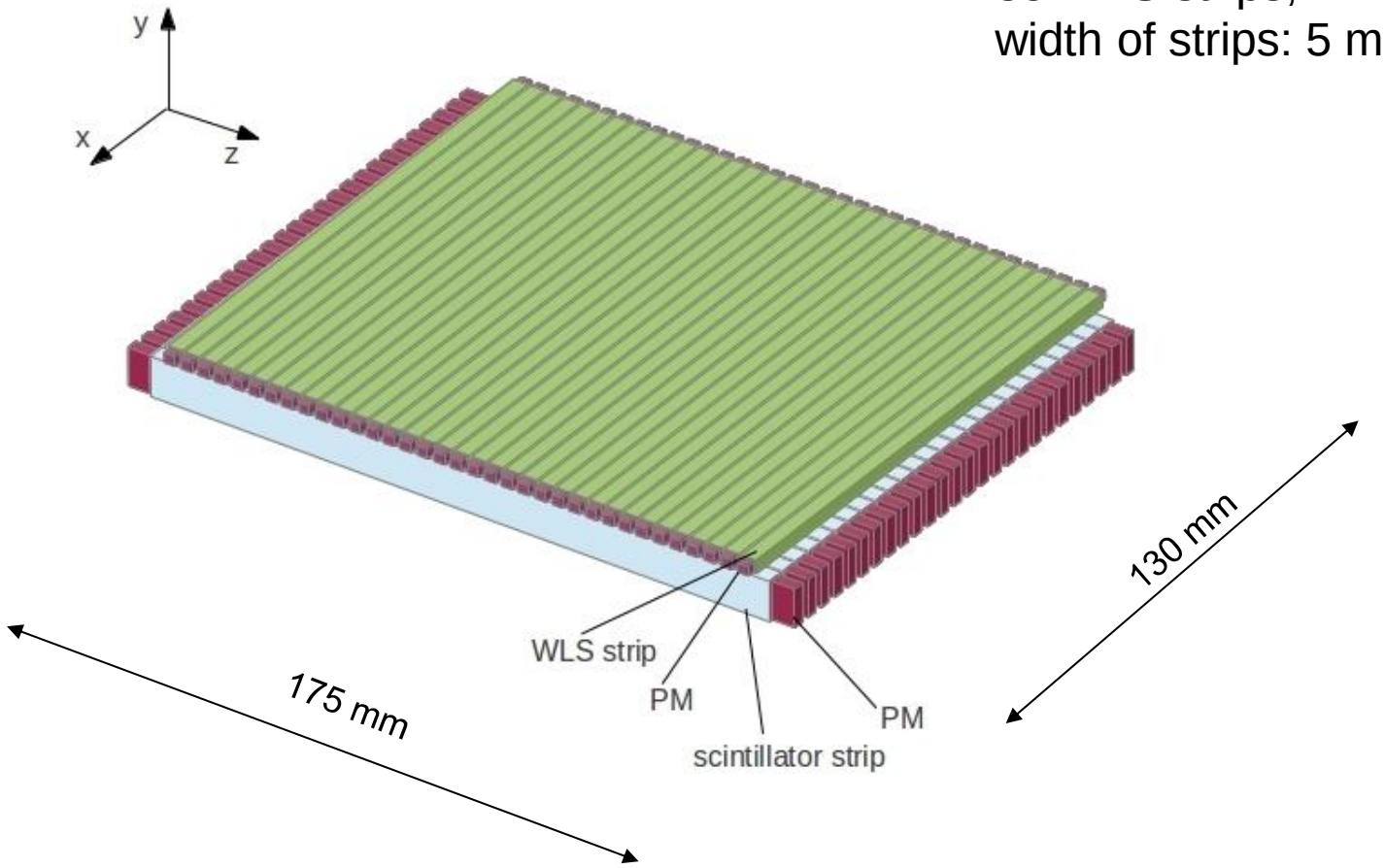
Δz~5mm (?)

$$y = \frac{n_{max} - 2n}{n_{max}} d/2$$

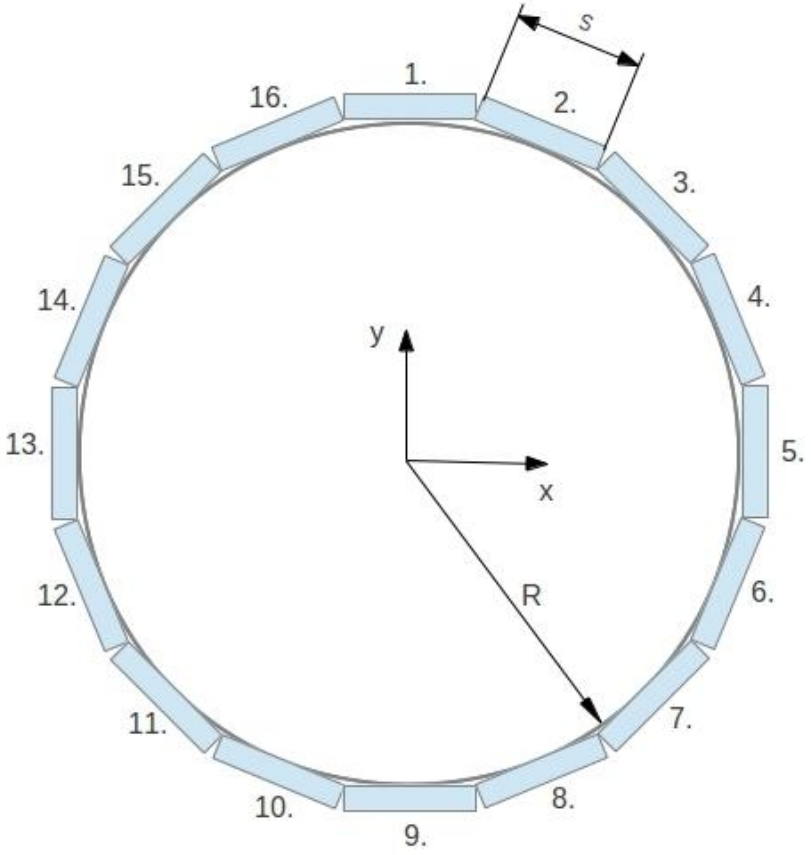
Depth of interaction (DOI)

Read out of scintillator strips

Example of a segment:
26 scintillator strips,
35 WLS strips,
width of strips: 5 mm

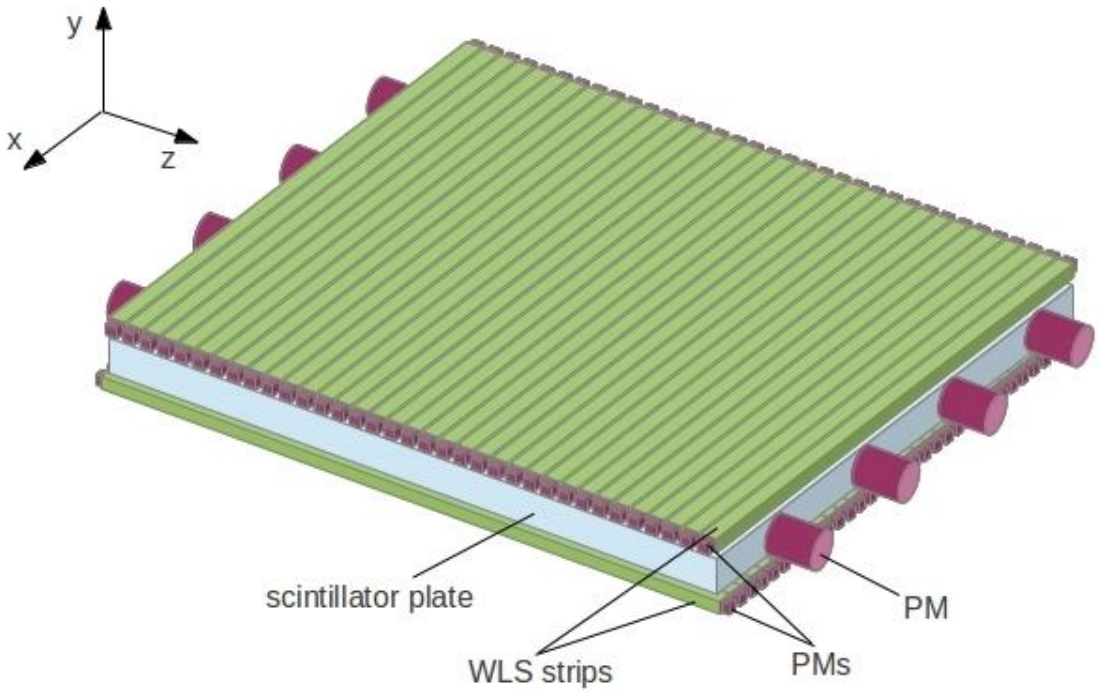


Arrangement of segments in tomograph

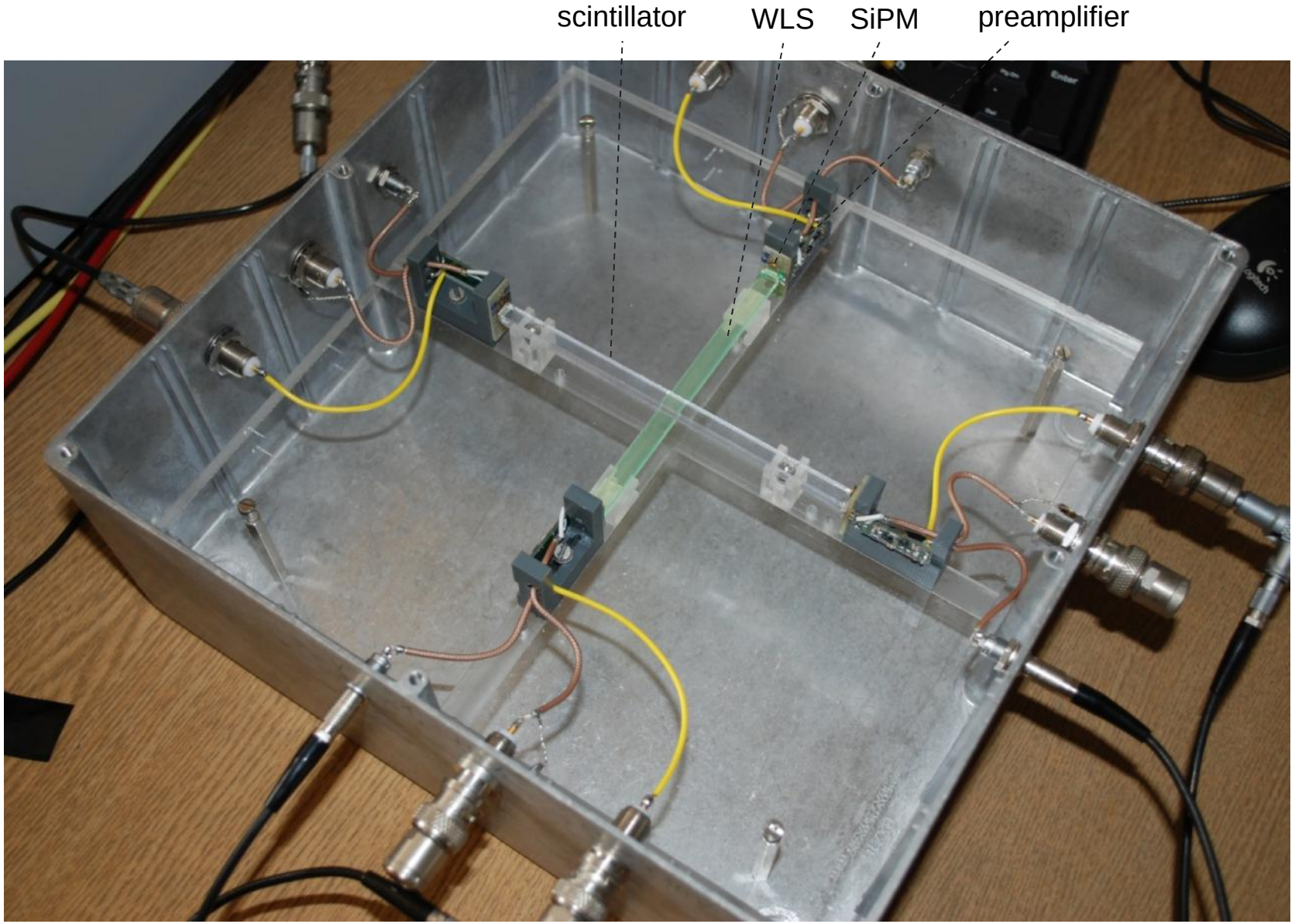


s = 130 mm,
R = 327 mm

Read out of scintillator plates

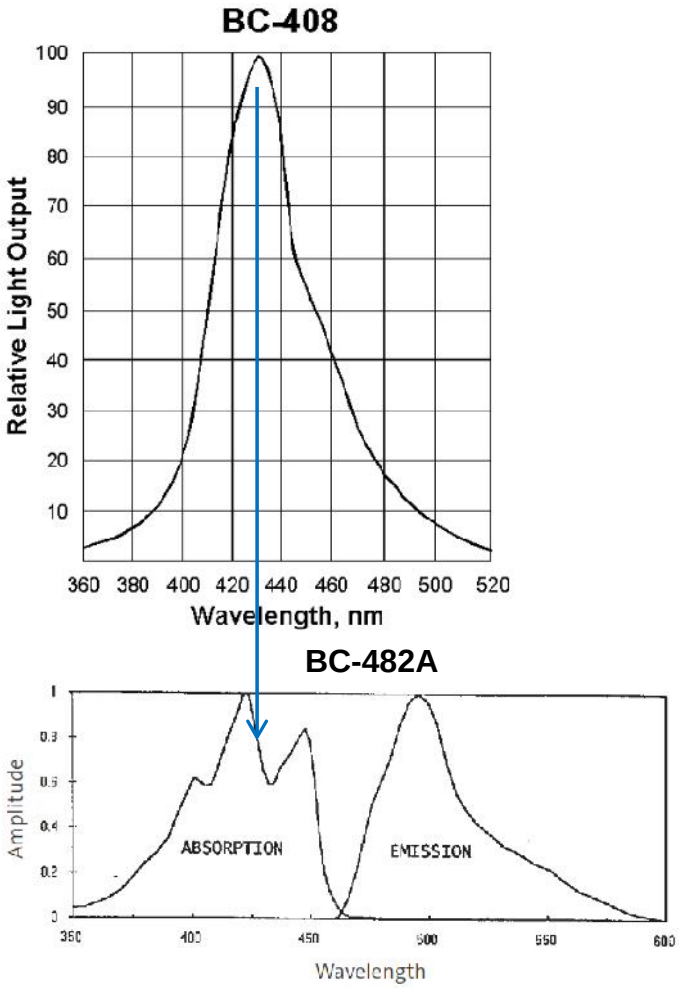


Test setup



Plastic scintillator and WLS

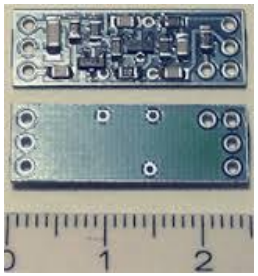
- Scintillator:
  - 5mm x 5mm x 120mm,
  - BC-408,
  - decay time 2.1 ns,
  - light yield ~ 9000 photons/MeV
- WLS:
  - 3mm x 6mm x 100mm,
  - BC-482A,
  - blue to green conversion,
  - quantum efficiency 86%,
  - decay time 12 ns



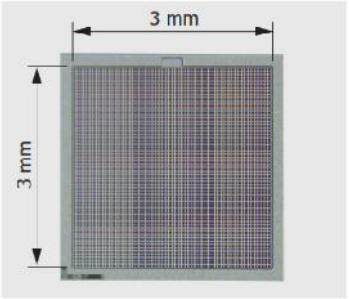
Silicon Photomultiplier (SiPM)

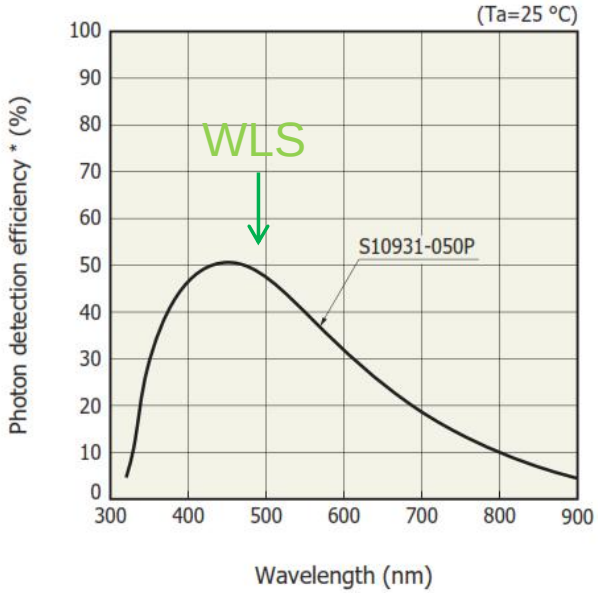
- SiPM:
  - Hamamatsu S10931-050P
  - Active area 3mm x 3mm
  - Number of pixels 3600
  - Fill factor 61.5%
  - Operating voltage ~70V
  - Dark count 6 Mcps
  - Time resolution (single photon) 500-600ps
  - Gain 7.5×10^5

- Preamplifier:
  - AMP-0611
  - Gain 10-20
  - Signal rise time 700 ps



Macrophotograph of SiPM





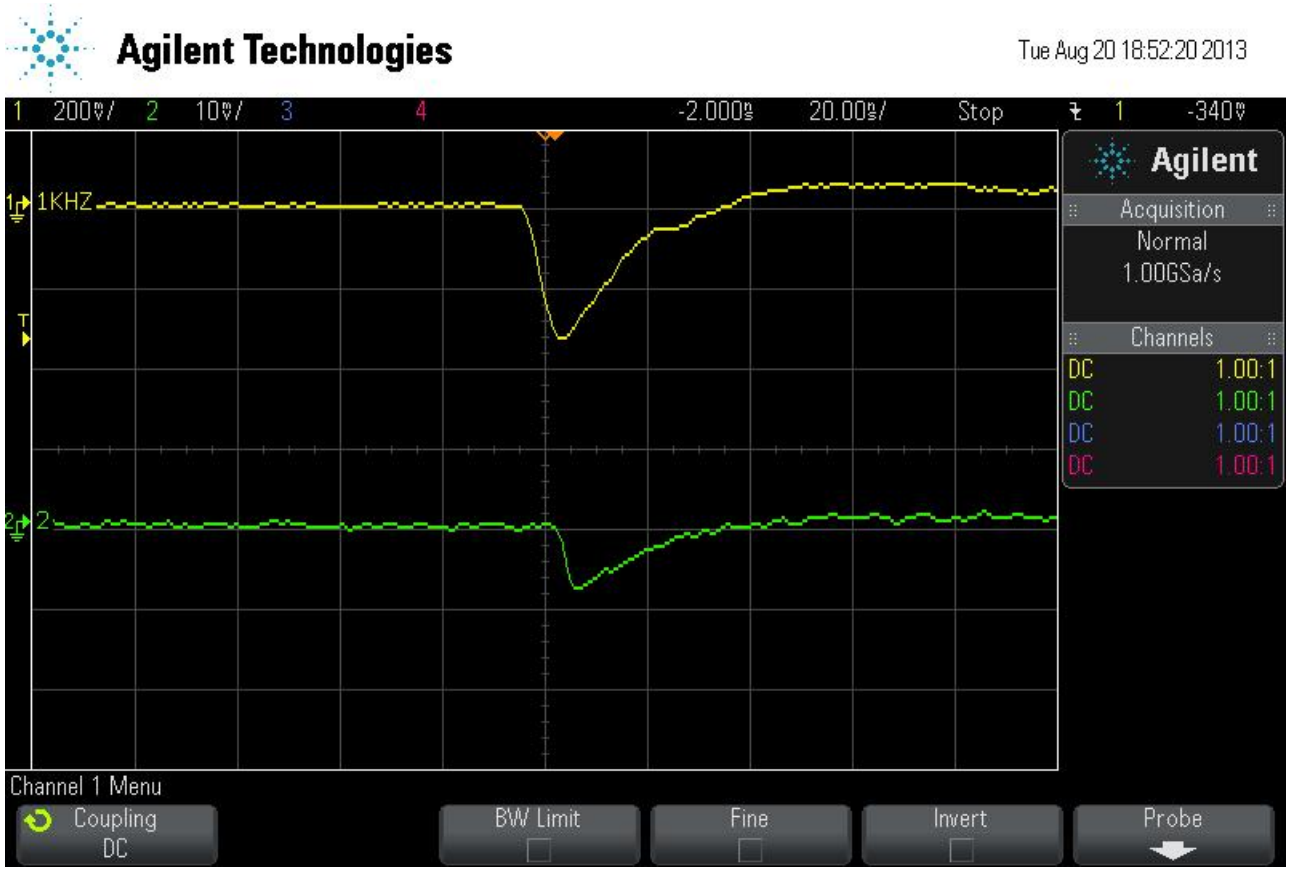
SiPM pulses


Agilent Technologies
InfiniiVision
DSO-X 2024A
200 MHz
1KHZ
Agilent
Acquisition
Normal
2.00GSa/s
Channels
Trigger Menu
Trigger
Edge
Source
1KHZ
Slope

Coincidences of plastic and WLS

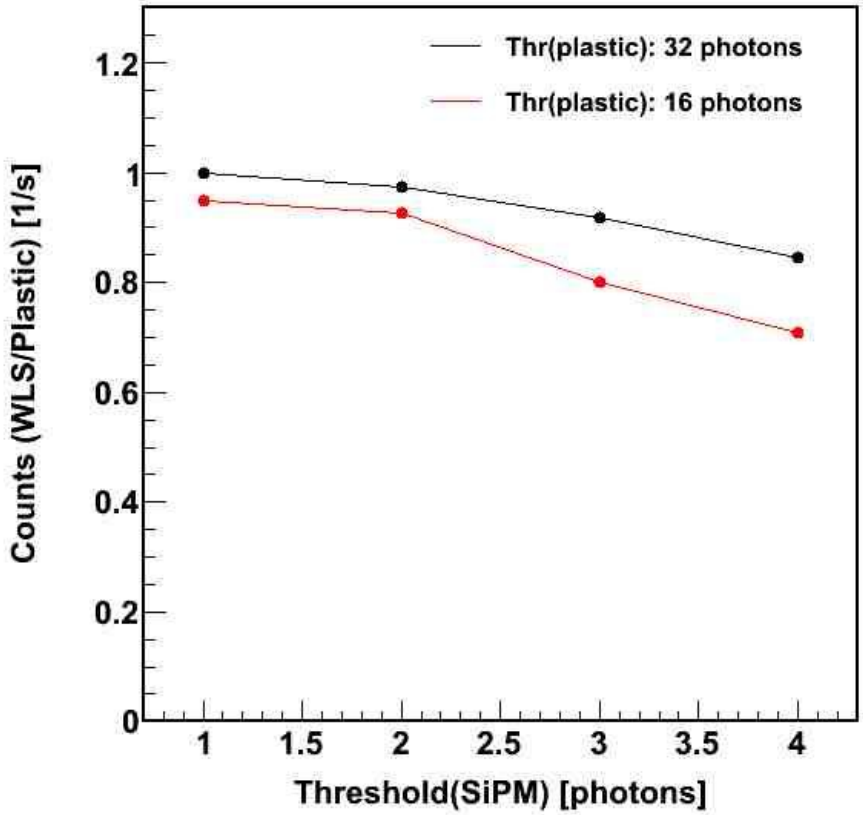
Plastic

WLS

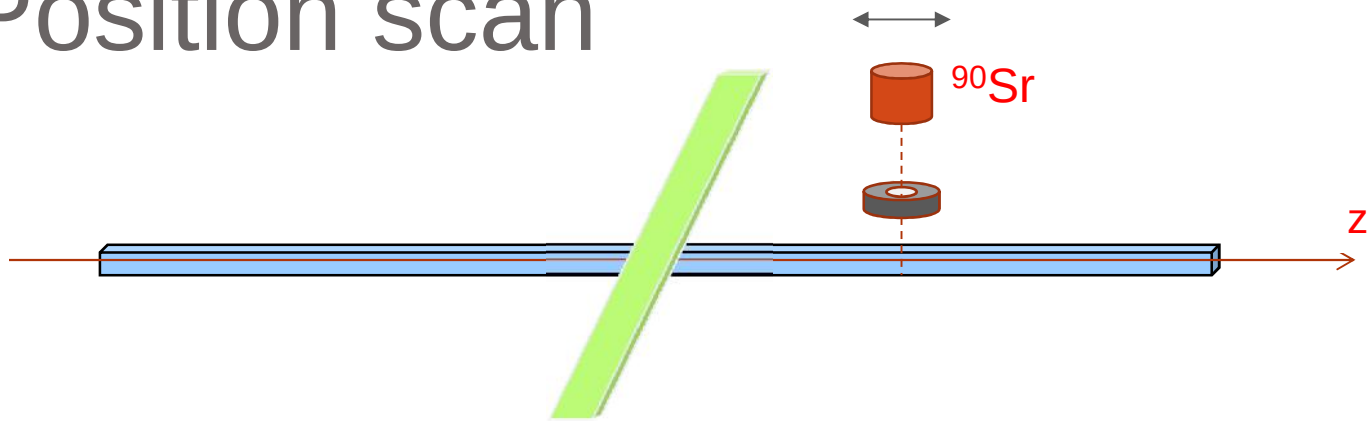


Coincidences of plastic and WLS

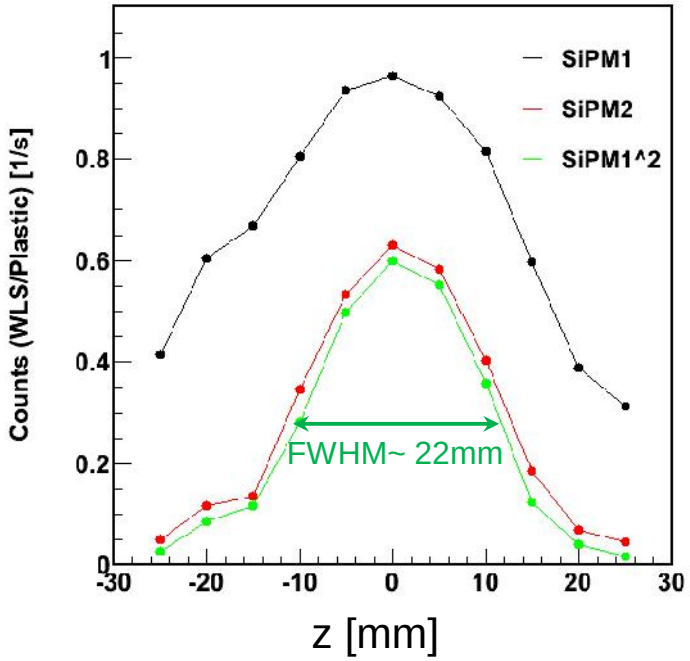
Radioactive source: ^{90}Sr



Position scan



SiPM1: 1 < threshold < 2 photons
SiPM2: 2 < threshold < 3 photons



Smearing due to:

- Collimation: ~ 6 mm
- WLS strip width: 6 mm
- angular range of registered photons: ~ 5 mm
- …

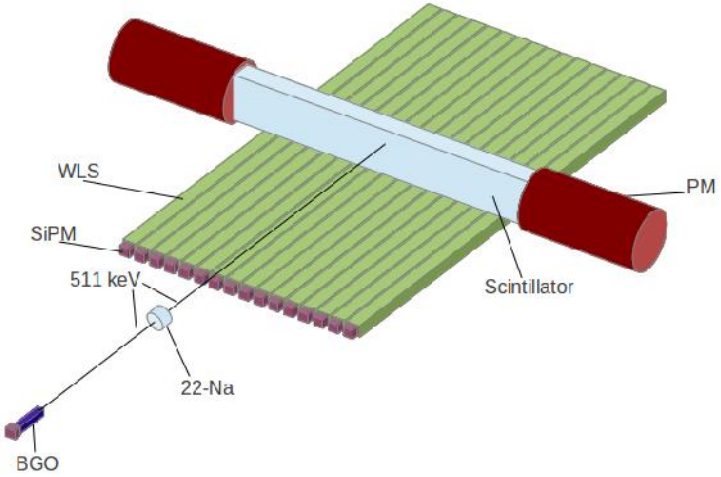
Number of photelectrons

Factor	Acceptance
Solid angle for photons registered in WLS	10%
Transmission scintillator/air (BC408, n=1.58)	96%
Transmission air/WLS (BC-482A, n=1.59)	96%
Absorption in WLS (thickness=3 mm, absorption length~4mm)	50%
Quantum efficiency of WLS	86%
Fraction of photons propagating towards one end of WLS	25%
Coverage of WLS face by SiPM	50%
SiPM fill factor	61.5%
SiPM photon detection efficiency	47%
Product	**0.143%**

For 0.3 MeV electrons originating from the Compton scattering of the 0.511 MeV quanta, number of scintillation photons in BC408 equals 9000/MeV x 0.3 MeV =2700. Number of photons registered with WLS equals to 2700 x 0.00142 ~**4**.

New test setup

- 16 WLS strips 3mm x 6mm x 100mm
- 3 times higher dye concentration
- one end coated with reflective film
- 511 keV quanta tagged from ^{22}Na
  tagged with 2x2x10mm3 BGO
- readout with QDC;
  single photoelectrons recorded
- trigger: threshold for a sum of WLS pulses



Conclusions

- Application of WLS strips has been proposed for a 3-D position reconstruction in the strip/matrix PET
- Coincidences of plastic scintillator and WLS strip observed in the first tests with ^{90}Sr source
- Small number of photons seems to be the main issue
- A setup including 16 WLS strips will be used to demonstrate applicability of the WLS readout for PET based on plastic scintillators.