Studies for improvement of TOF – PET and SiPM related work

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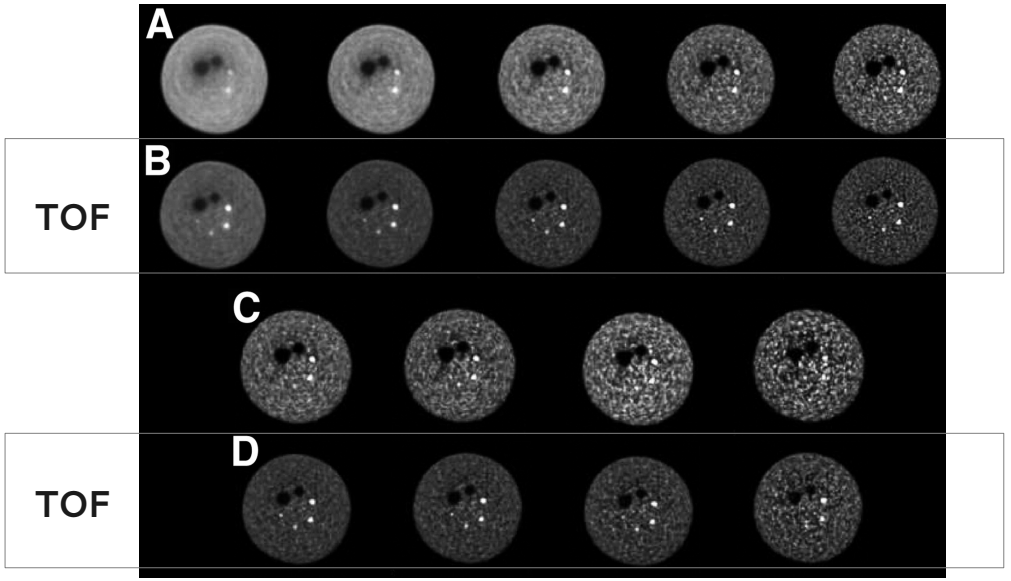
TOF for PET

Advantages of TOF for PET:

- Improved SNR
- Shorter acquisition times
- Lower dose for patients

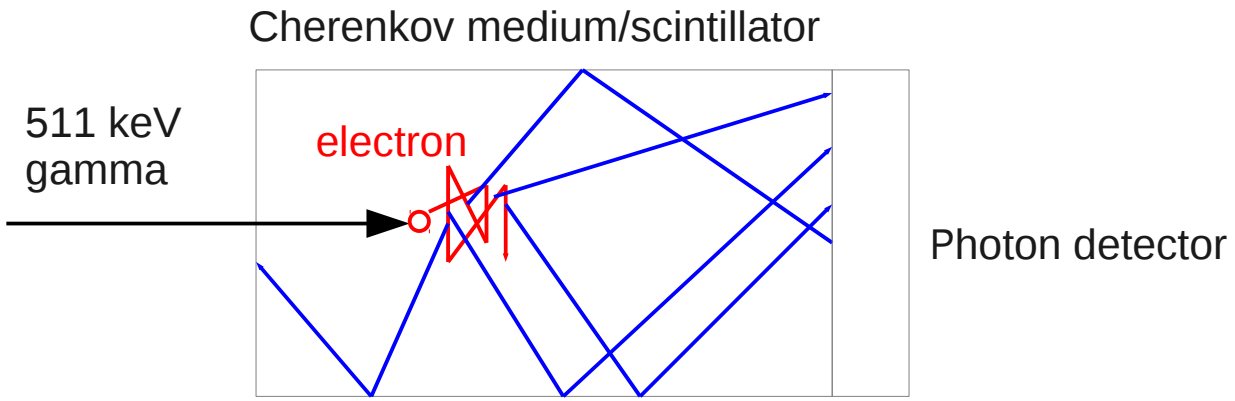


State of the art:

- 500-600ps FWHM CTR of commercial systems
- ~100ps CTR FWHM for laboratory systems

A...Non-TOF, 5min scan time,
1, 2, 5, 10, 20 iterations
B...TOF, 5min scan time,
1, 2, 5, 10, 20 iterations
C...Non-TOF, 10 iterations,
5, 3, 2, 1 min scan time
D...TOF, 5 iterations,
5, 3, 2, 1 min scan time
Ref: Karp: "Benefit of TOF in PET: Experimental and Clinical Results," JNM 49, 2008

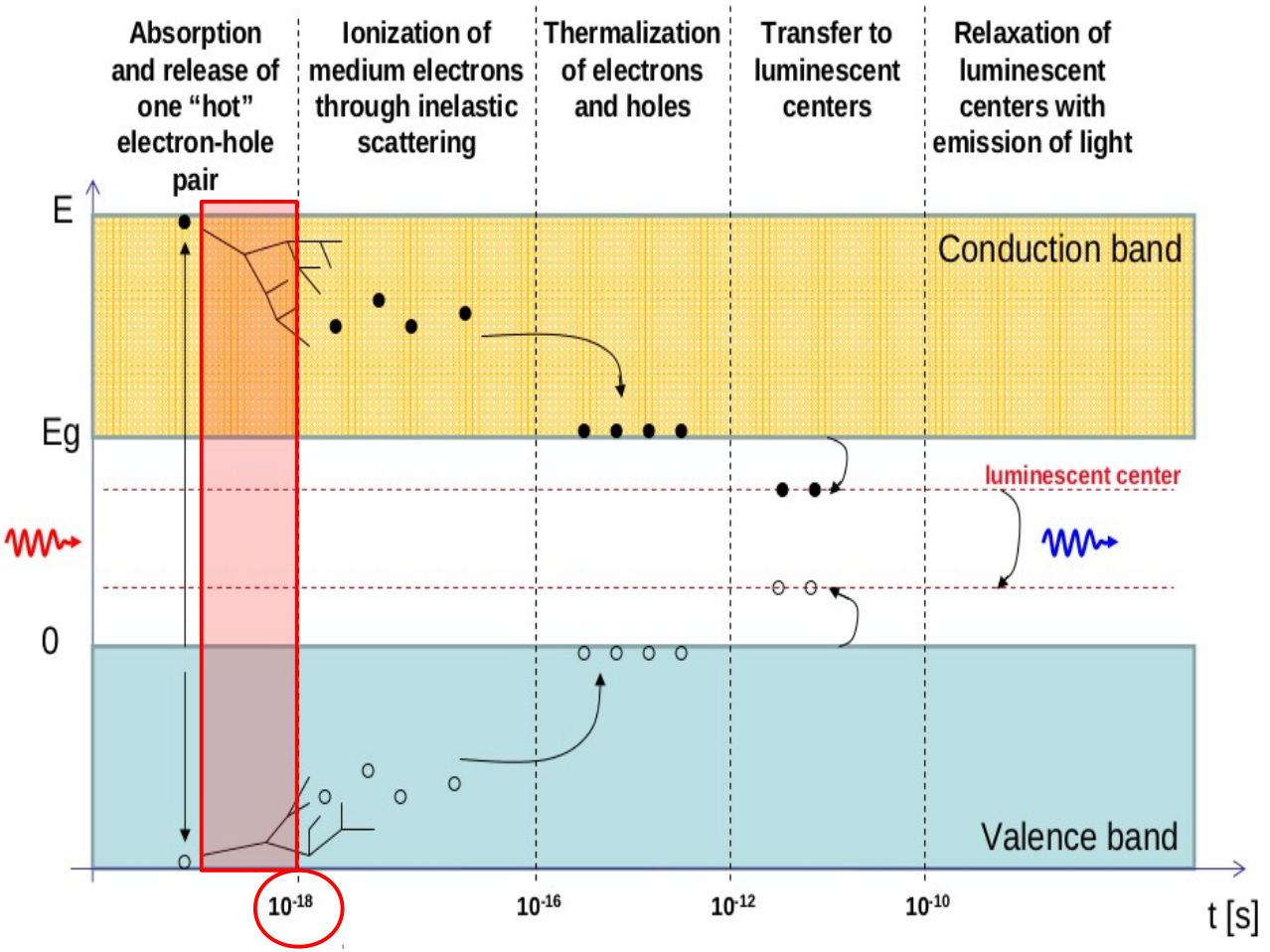
Cherenkov effect for TOF-PET



	Refractive Index	Density $[g/cm^{-3}]$	Threshold Energy $[keV]$	Electron Range $[\mu m]$	# of Cherenkov Photons
LSO	1.82	7.4	101	243	27
LuAG	1.84	6.7	98	260	28
PWO	2.2	8.28	63	219	23

Table Characteristics, electron ranges and number of Cherenkov photons produced by an incident 511keV γ-ray.

Cherenkov effect for TOF PET

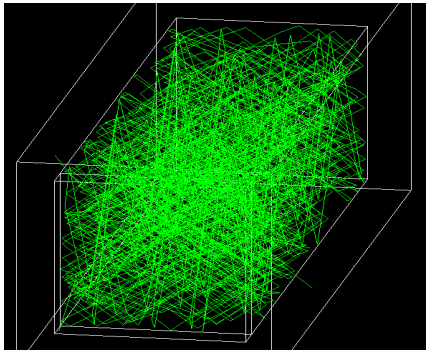


Courtesy of
F. Powolny

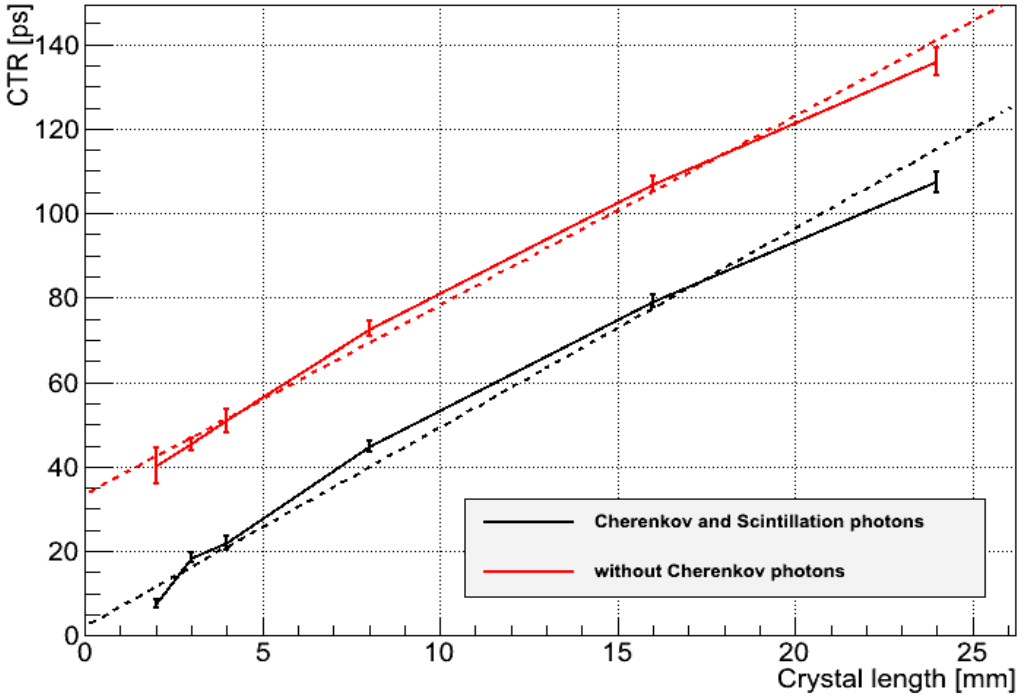
Cherenkov effect is instantaneous compared to scintillation!

Cherenkov effect for TOF-PET

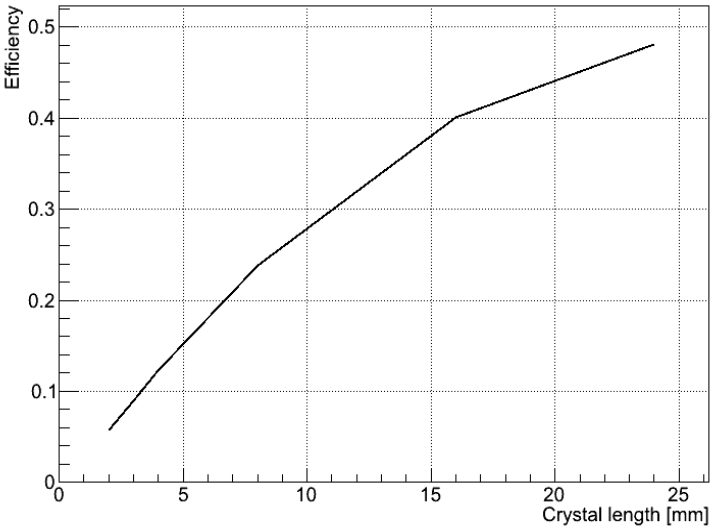
Geant 4 simulations of basic coincidence setup
with various crystal lengths:



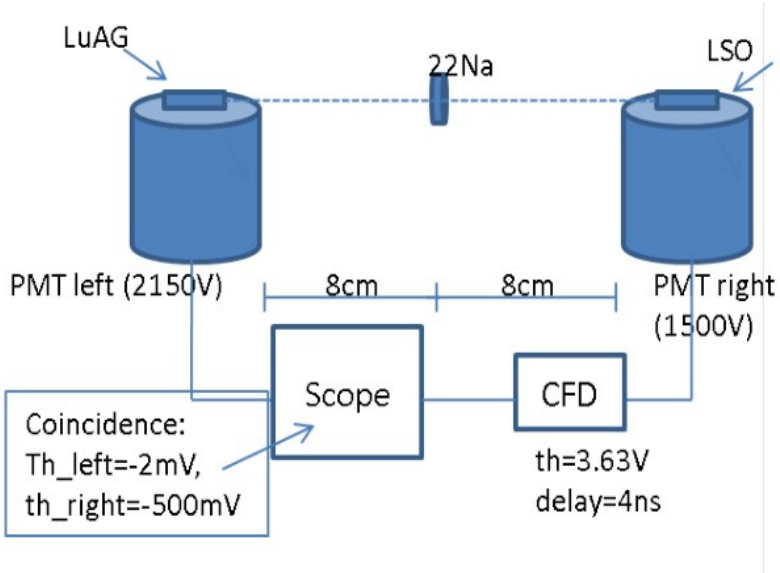
Coincidence Time Resolution



gamma detection efficiency at 511 keV



Cherenkov effect for TOF-PET Experiment:



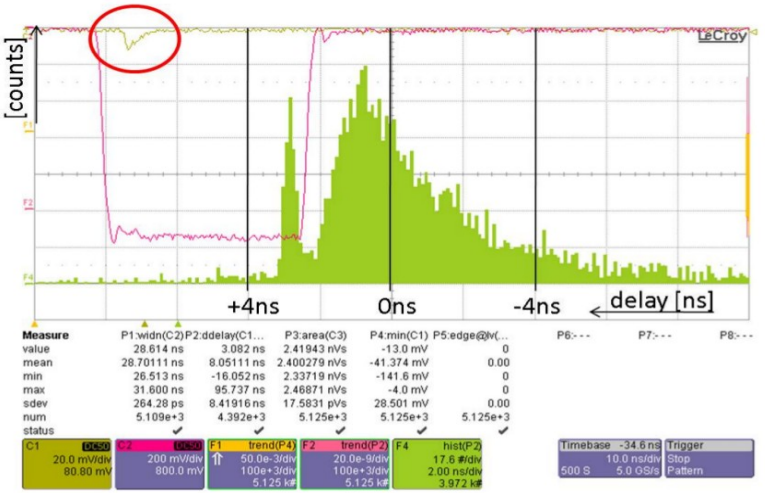
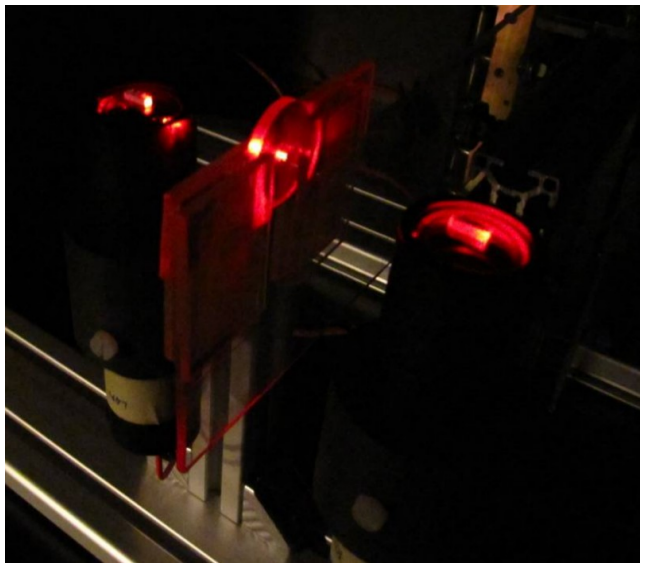


Figure 3.15: Screenshot of the delay measurement with the doped LuAG:Ce crystal versus LSO:Ce.



Crystal 1	Crystal 2	Size $[mm^3]$	Detector	Scintillation mechanism	Time resolution $FWHM_{coinc}$ $[ps]$
LSO:Ce	LSO:Ce	2x2x10	PMT-CFD	Scintillation	355
LFS:Ce	LSO:Ce	3x3x15	SiPM-NINO	Scintillation	390
LuAG	LSO:Ce	2x2x8	PMT	Cherenkov	425
LuAG	LuAG	2x2x8	PMT	Cherenkov	251

SiPMs for Cherenkov-TOF-PET

Advantages

- Small
- Insensitive to magnetic fields --> MRI
- Fast

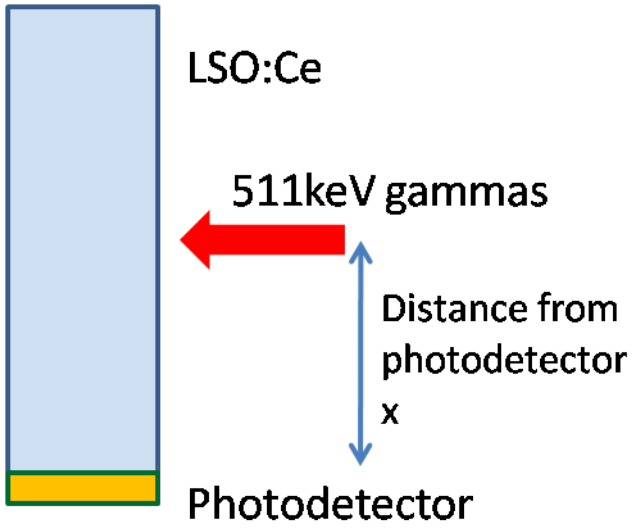
Disadvantages

- High dark count rate
- Need good electronics
- Not so fast on a single photon level

Studies on photon arrival times in scintillators

Motivation:

W. W. Moses and S. E. Derenzo, “Prospects for Time-of-Flight PET using LSO Scintillator *,” IEEE Transactions on Nuclear Science, vol. 46, no. 3, pp. 474–478, 1999.



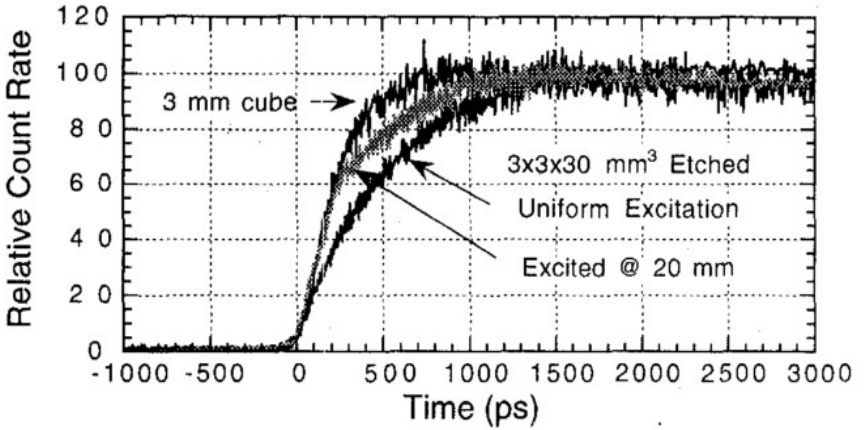
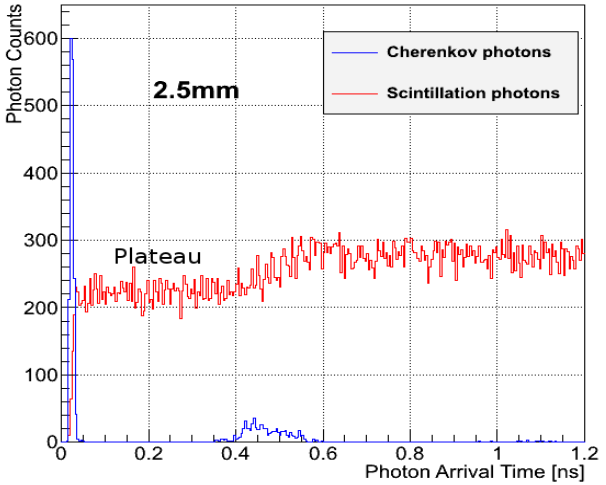
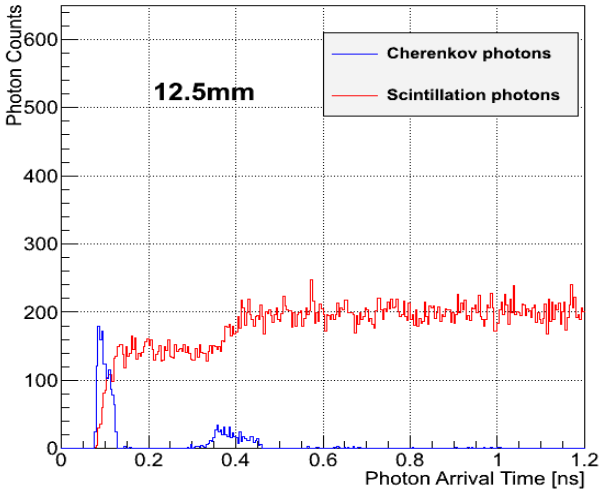
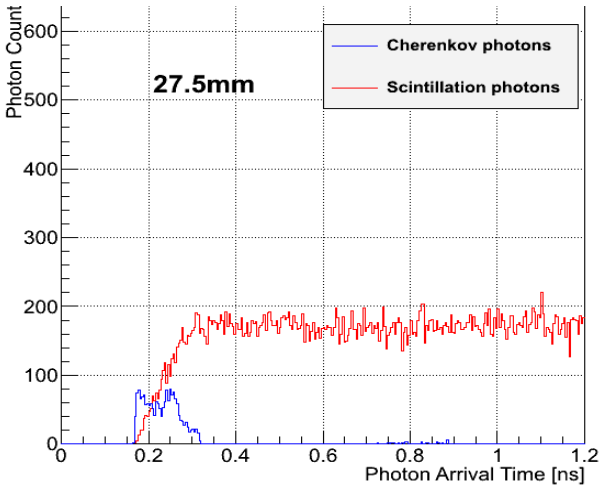


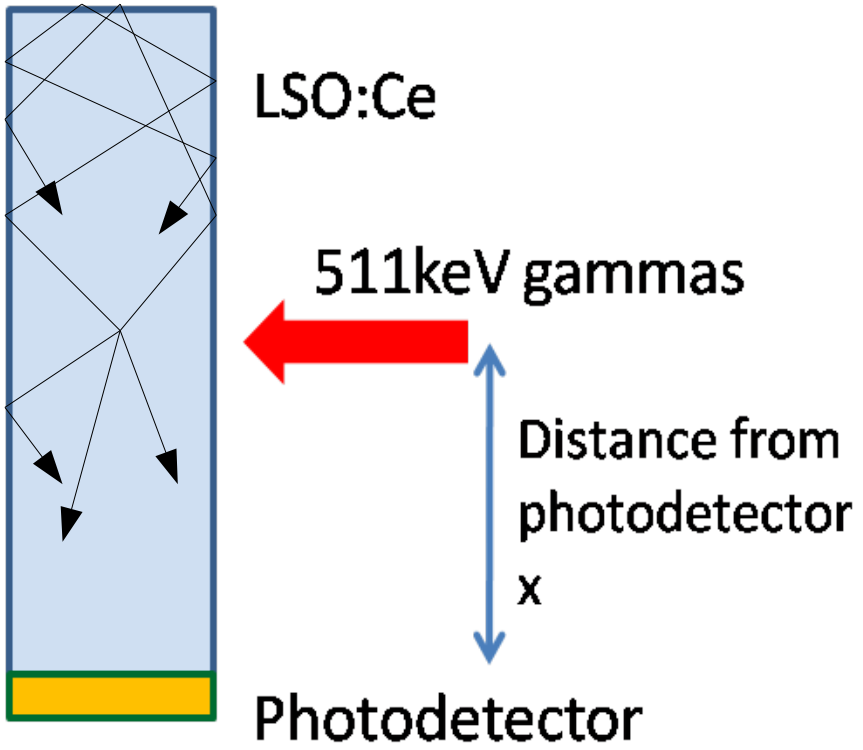
Figure 10. Scintillation photon arrival time distribution for a 3x3x30 mm^3 etched LSO crystal illuminated with x-rays 20 mm depth compared to those from uniformly illuminated crystals.





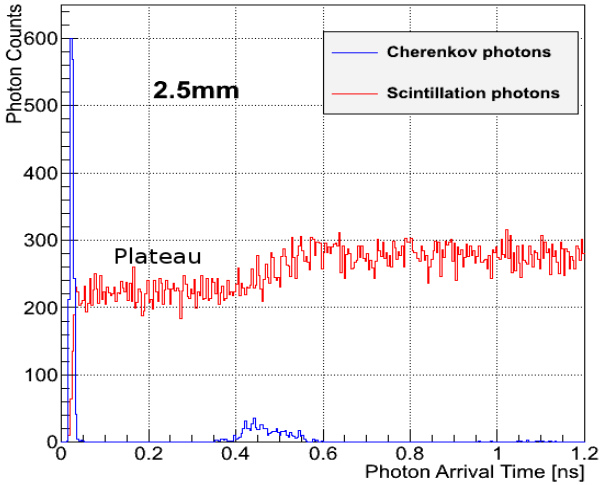


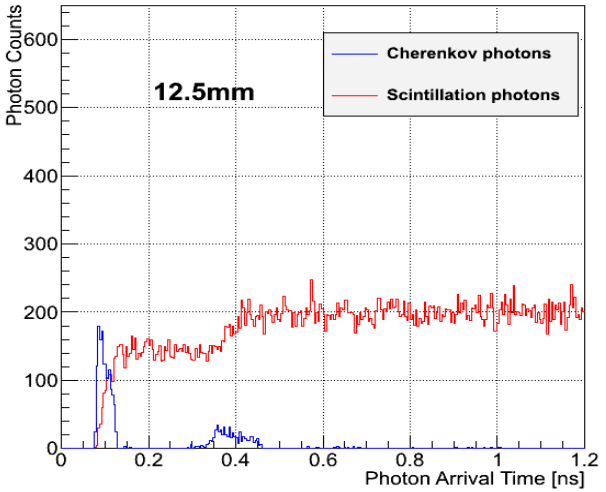
Photon arrival times

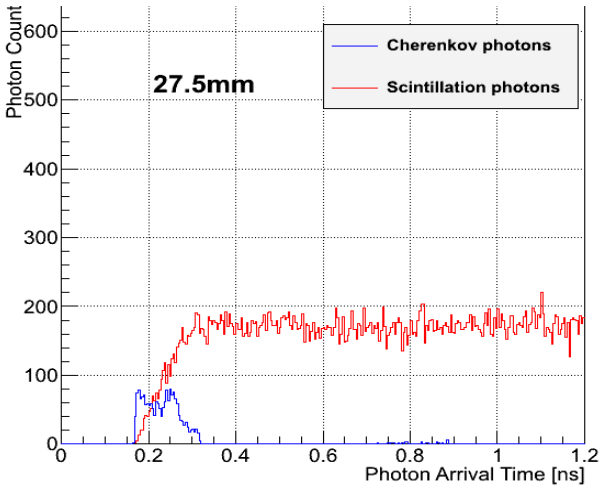


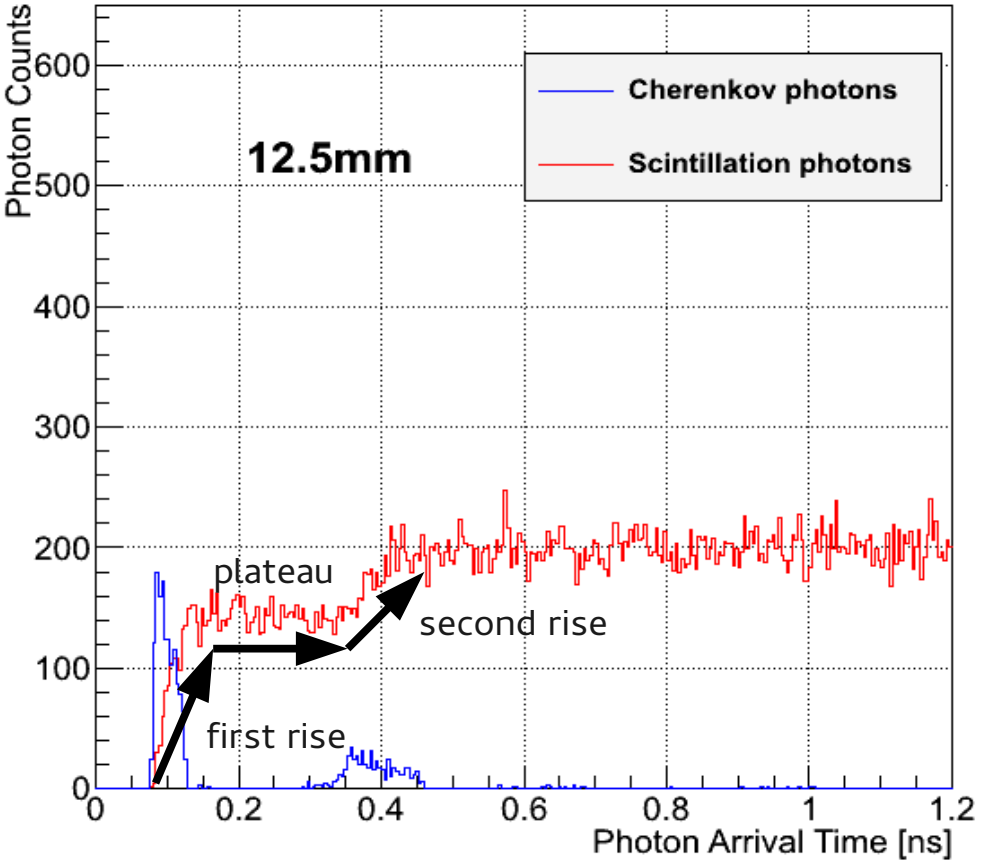
accumulated for 10000 gammas
+ discriminated for 511 keV

Photon arrival times









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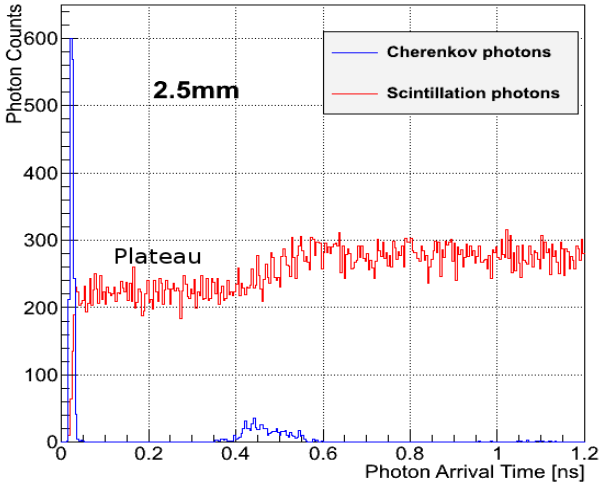
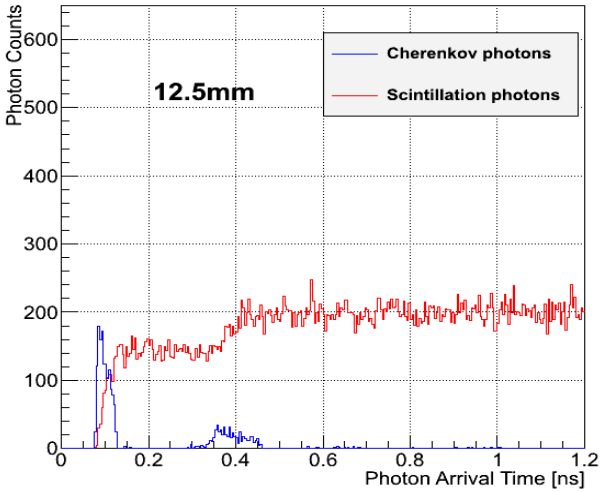
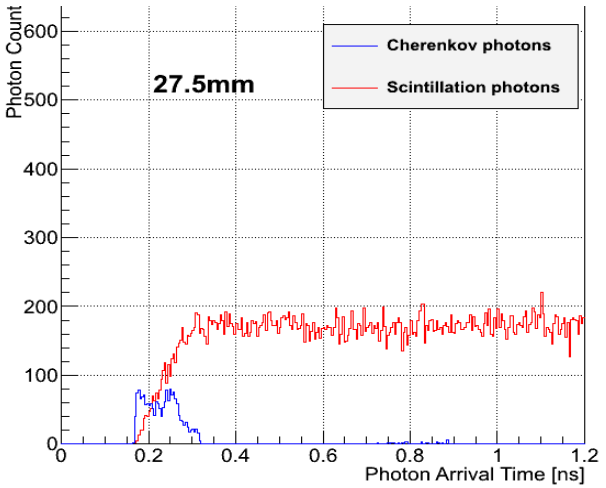
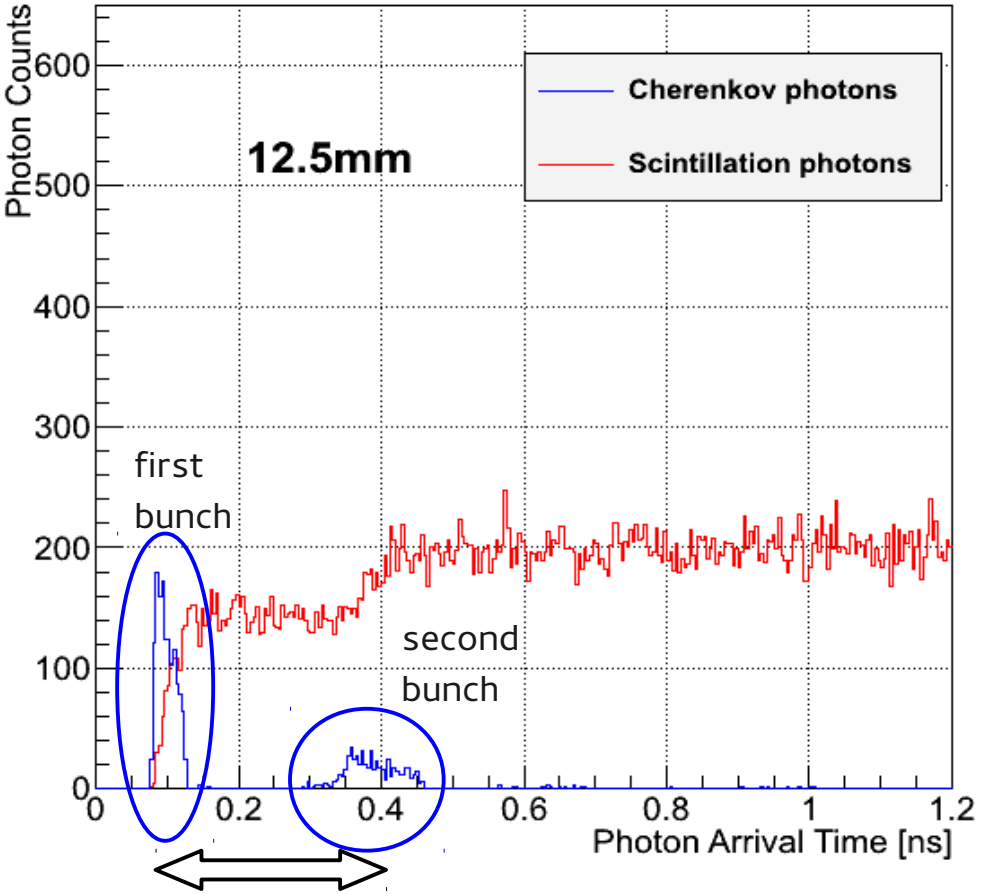




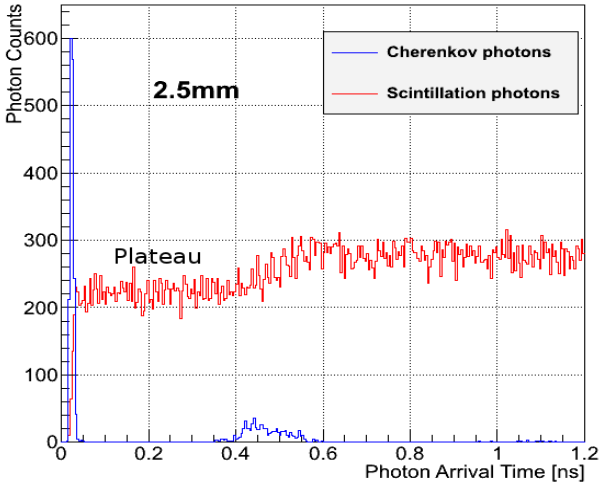


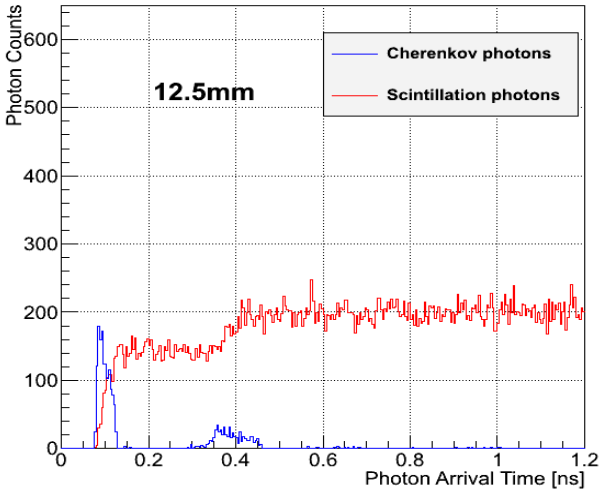
Photon arrival times

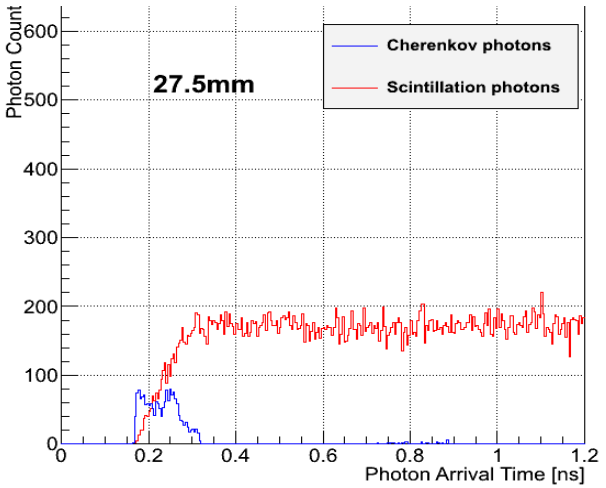


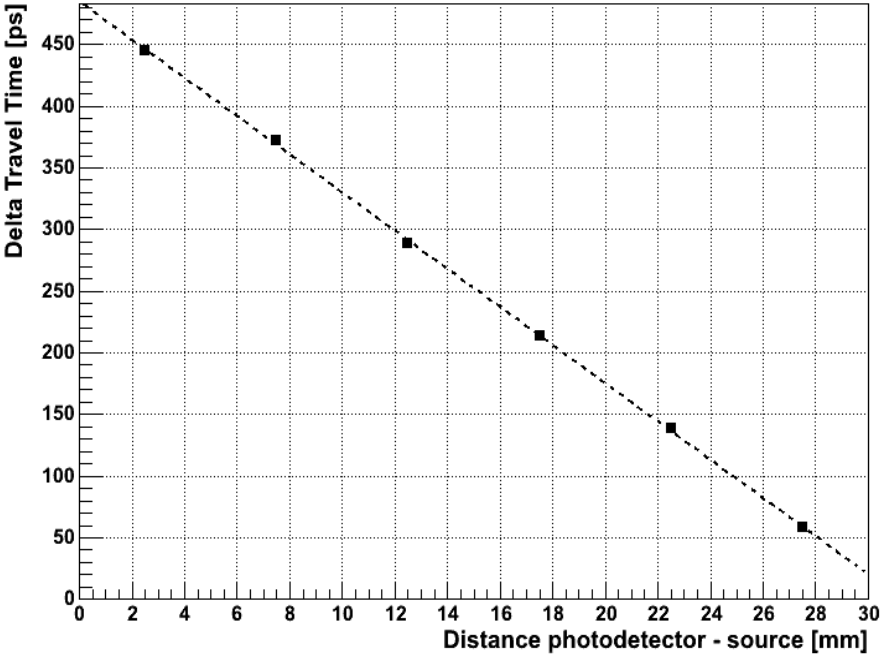
delta arrival time

Dependent on the DOI!







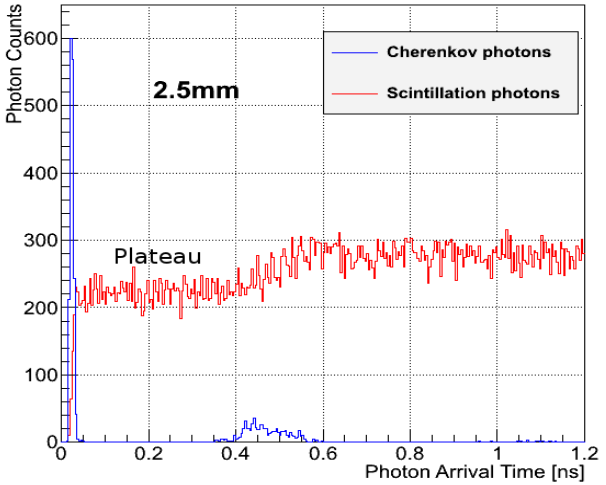


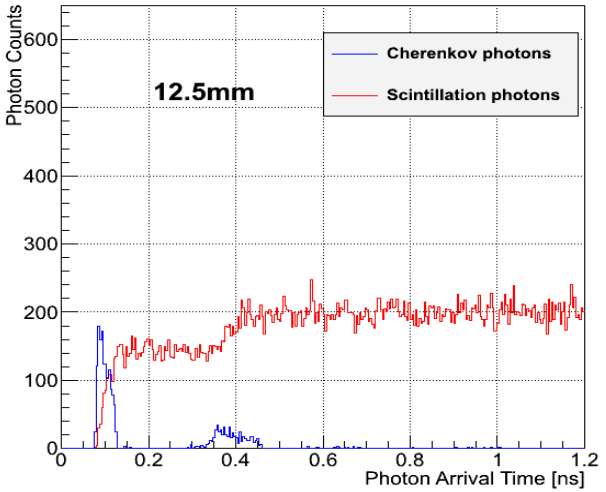
Delta arrival time is dependent on the DOI!

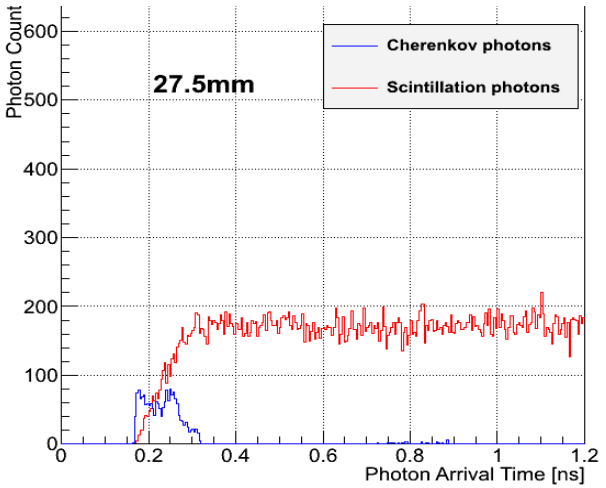
DOI determination by pulse shape analysis

For PET:
Reduction of parallax errors
Improvement of spatial resolution

Photon arrival times







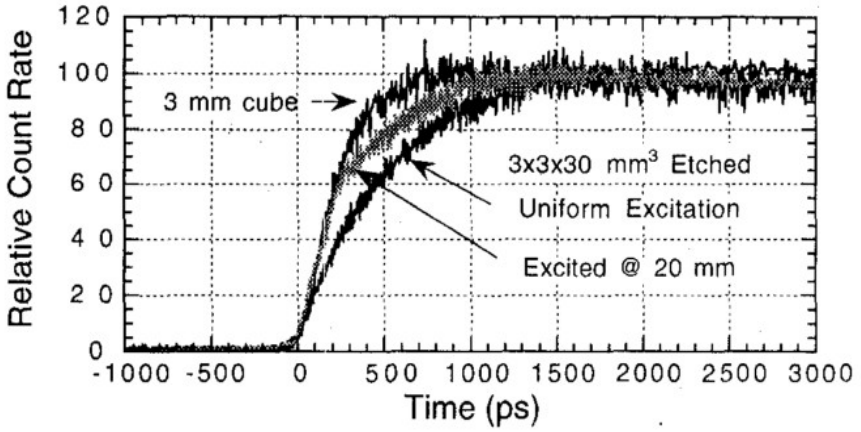


Figure 10. Scintillation photon arrival time distribution for a 3x3x30 mm^3 etched LSO crystal illuminated with x-rays 20 mm depth compared to those from uniformly illuminated crystals.

W. W. Moses and S. E. Derenzo, “Prospects for Time-of-Flight PET using LSO Scintillator *,” IEEE Transactions on Nuclear Science, vol. 46, no. 3, pp. 474–478, 1999.

Recent SiPM related activities

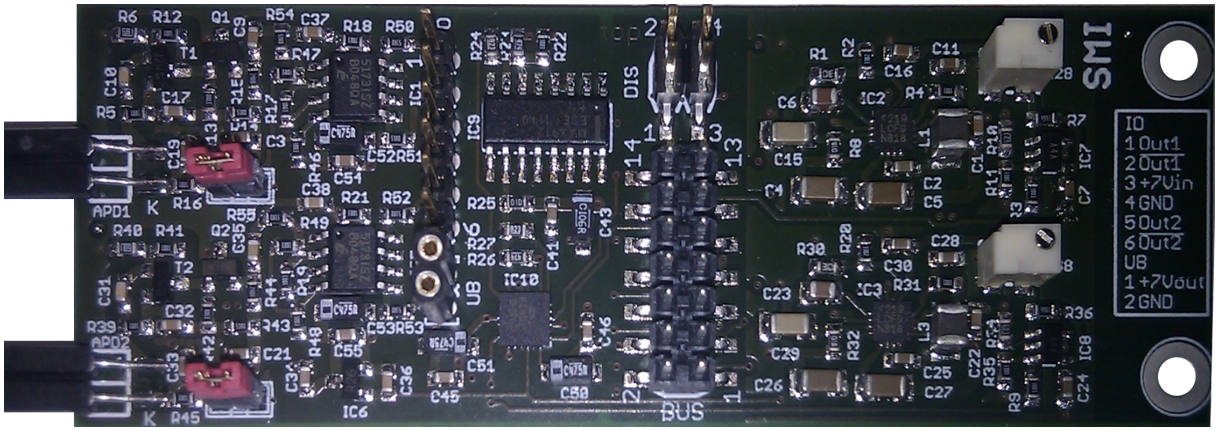
SiPM preamplifiers at SMI:

- Photonique
- Copy of Photonique preamp with minor modifications
- Bias voltage supply on board, manually controlled with potentiometer
- Adding second channel on the preamp board

⇨ **at the moment: development of a computer controlled preamplifier–discriminator board**

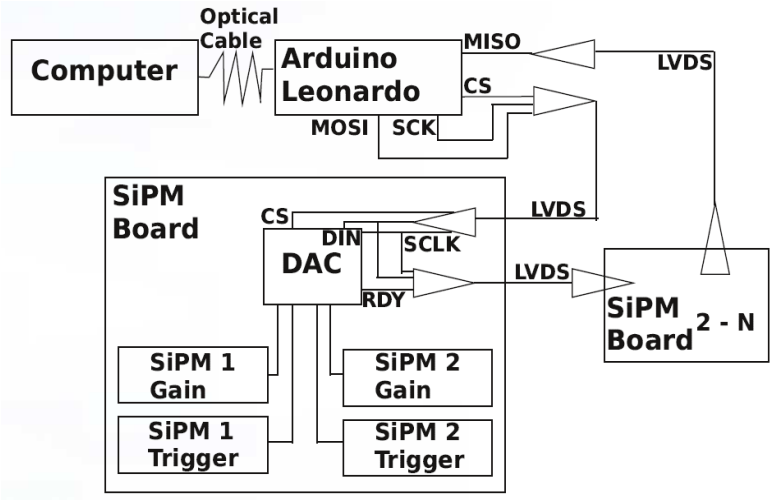
Development of preamp boards

- Computer controlled gain, bias voltage can be changed in steps of 0.2 mV
- Computer controlled trigger threshold for each channel: threshold can be changed in steps of 0.1 mV within 0 mV and 400 mV
- Each channel provides time over threshold
- Analogue output and discriminator output use LVDS



Development of preamp boards

- Daisy chaining of new boards, with SPI bus, driven by LVDS
  →up to 256 channels can be controlled by one master board
- Master board is an Arduino Leonardo (20€)
- No ground connection → robust against noise no ground connection
- Costs for the boards estimated 50€ per channel



Thanks to C. Sauerzopf and H. Schneider

Dual readout of SiPMs

Wish:

Increase the distance between SiPM and electronics
for highly granular detectors, improve timing

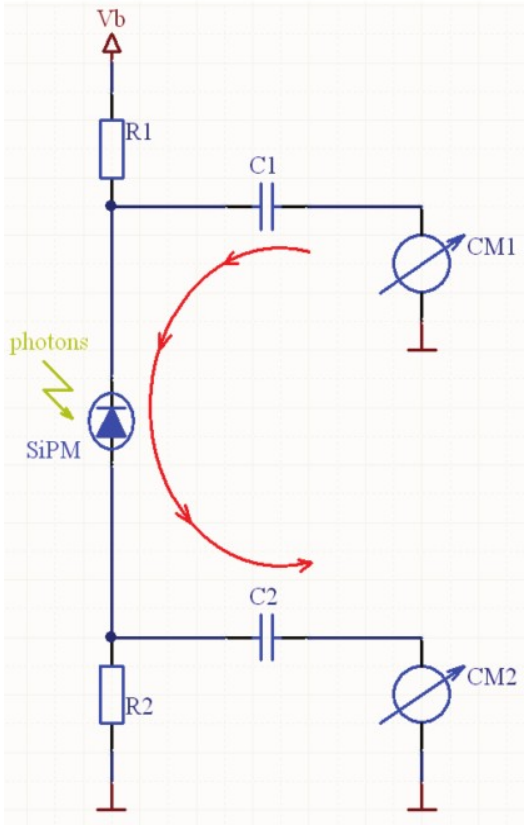
Problem:

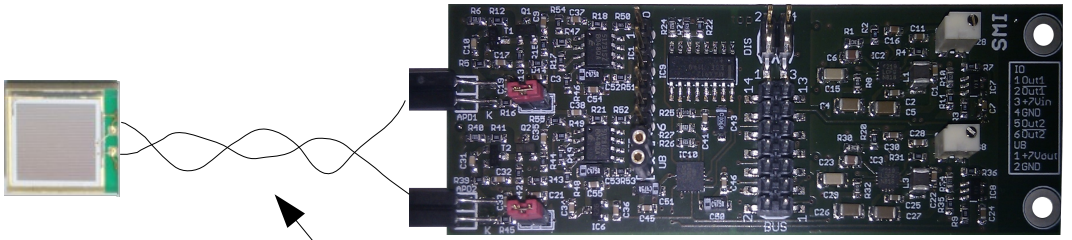
Lots of pick up noise at connection between SiPM an preamp
already with short connection

Solution:

Make us of the symmetric properties of SiPMs by simultaneous anode and cathode readout
→ LVDS signal, amplify both signals and subtract

Dual readout of SiPMs



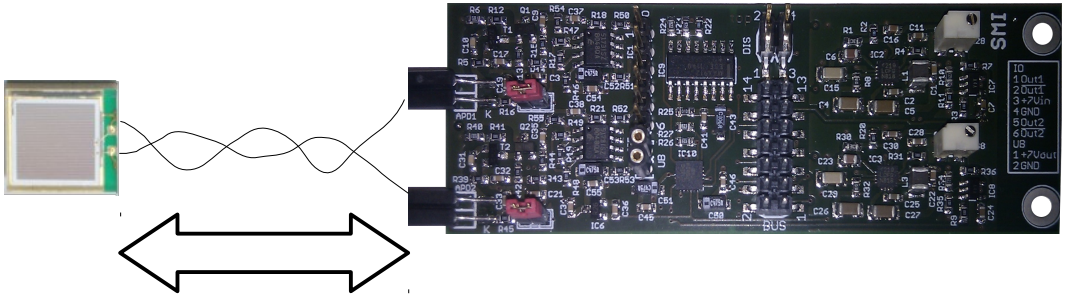


Twisted pair cable

Change of just one resistor
and one connection

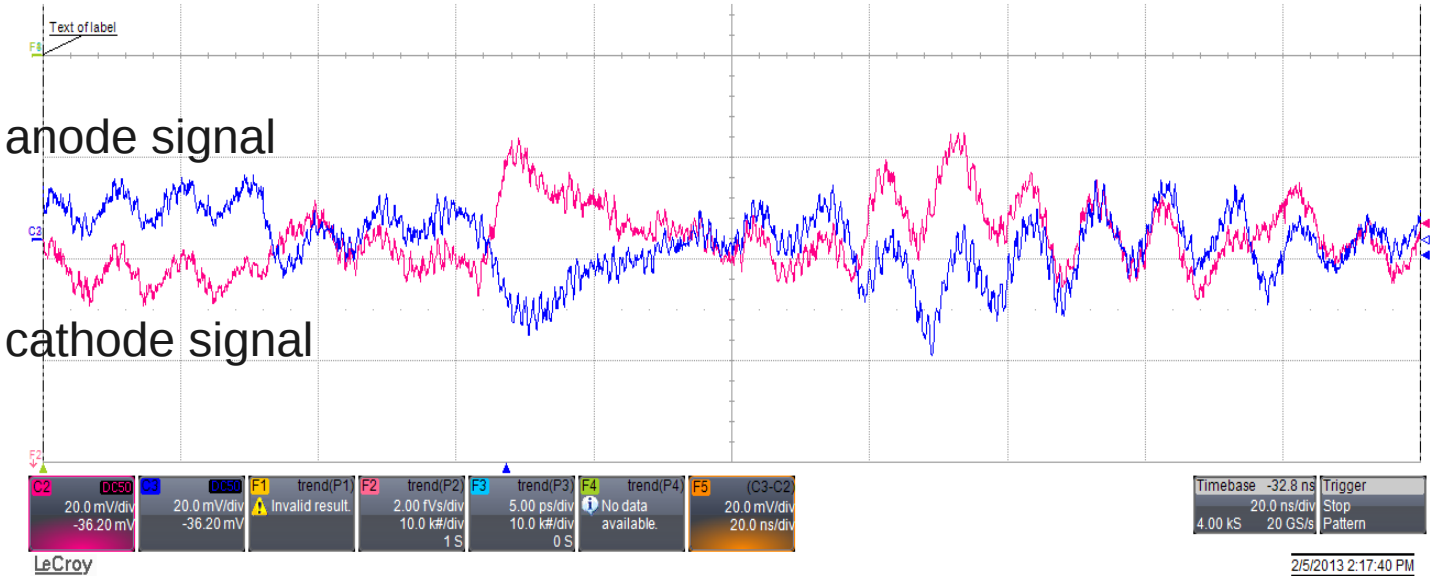
Reference
C. Parl, H. Larue, M. Streun, and K. Ziemons, “Double-Side-readout technique for SiPM-matrices,” IEEE Nuclear Science Symposuim & Medical Imaging Conference, pp. 1486–1487, Oct. 2010.

Dual readout of SiPMs

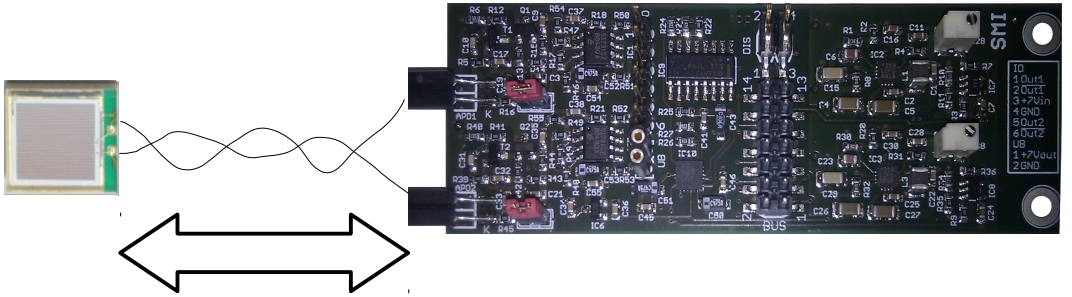


10 cm twisted pair cable

Lots of pick up noise:



Dual readout of SiPMs

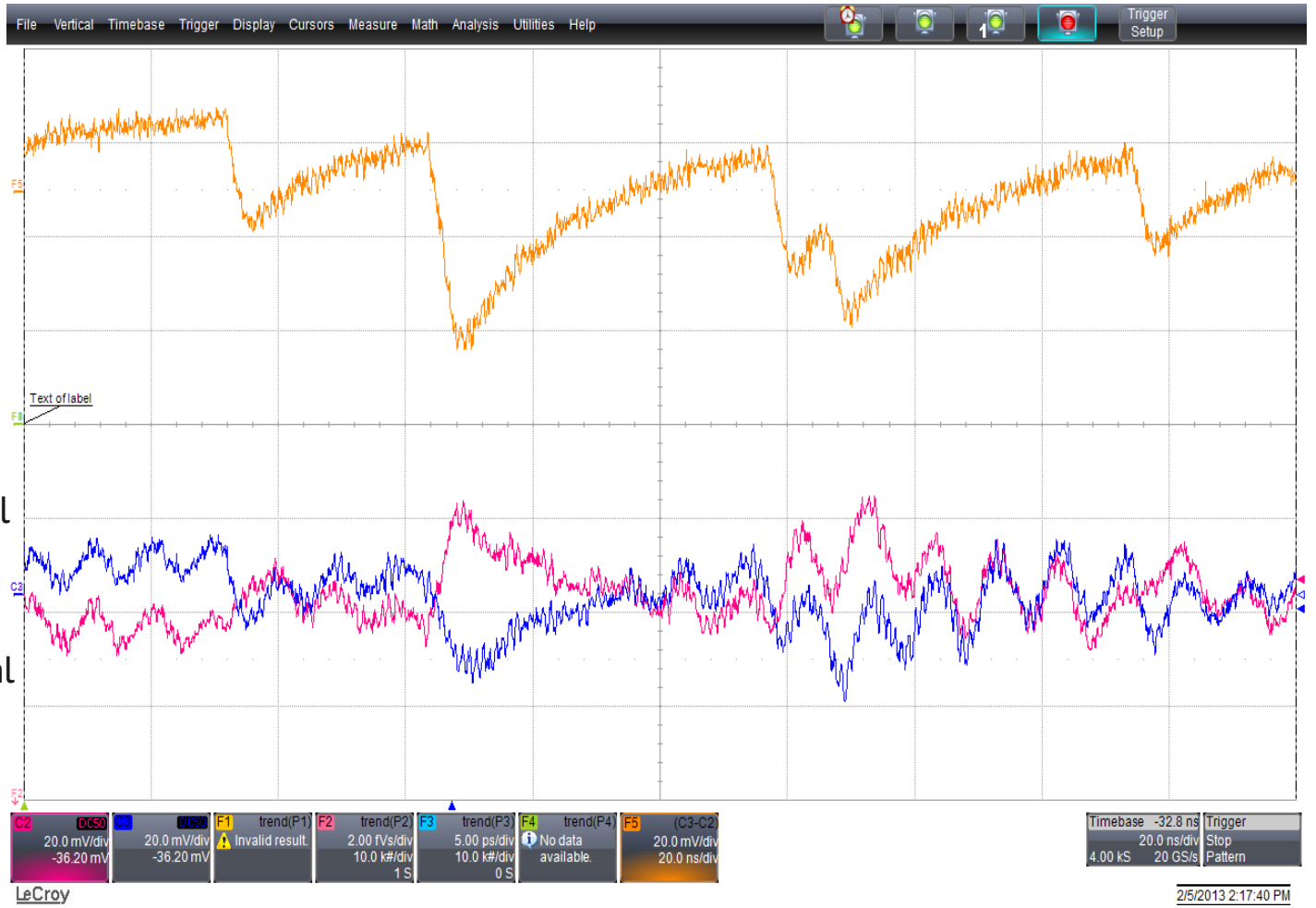


10 cm twisted pair cable

difference of the signals

anode signal

cathode signal



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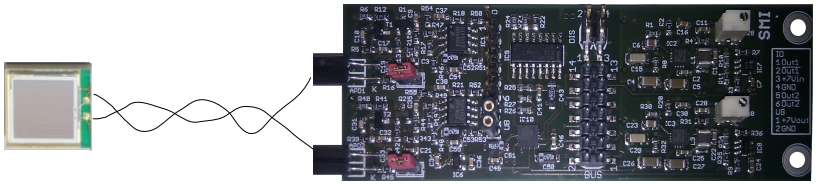

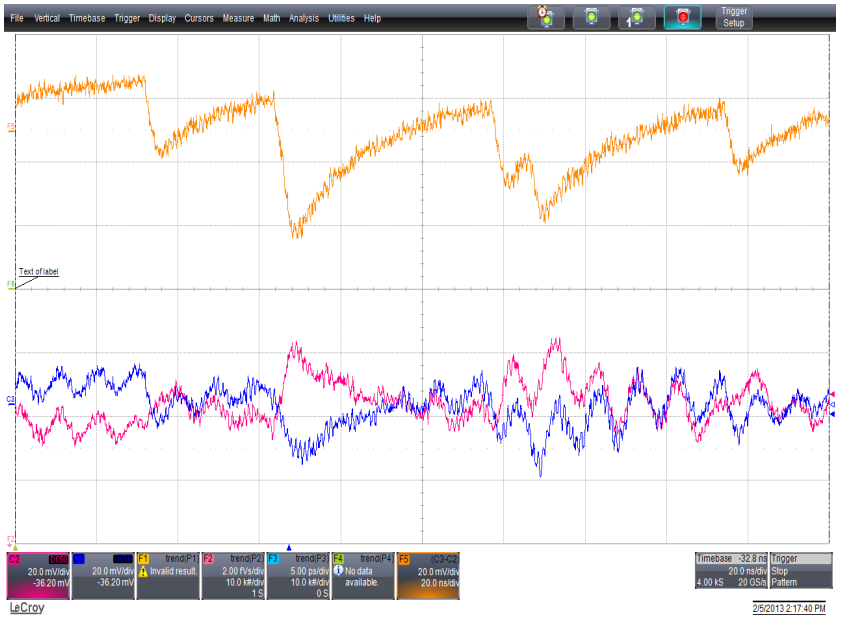

- Reduction of pick up noise
- Improved timing by steeper rising/falling edge
- Possibility to increase distance between SiPM and preamp

Thank you for your attention!

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