Fast SiPM readout for PET

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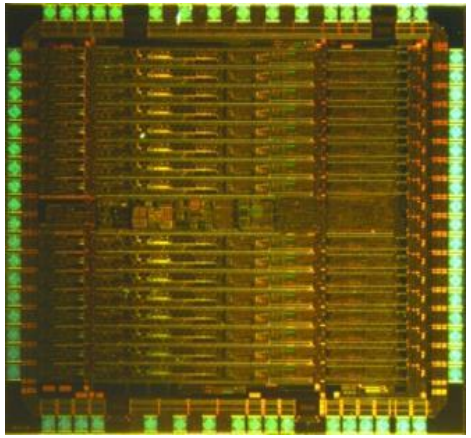
Outline

- The FlexToT ASIC
  - FlexToT jitter
- Results with 1 channel MPPC
  - Energy Resolution
  - FlexToT measurements at CERN
  - DOI
- First results with monolithic and MPPC matrix
  - Energy Resolution
  - CRT
- MPPC characterization
- Future steps

The FlexToT ASIC

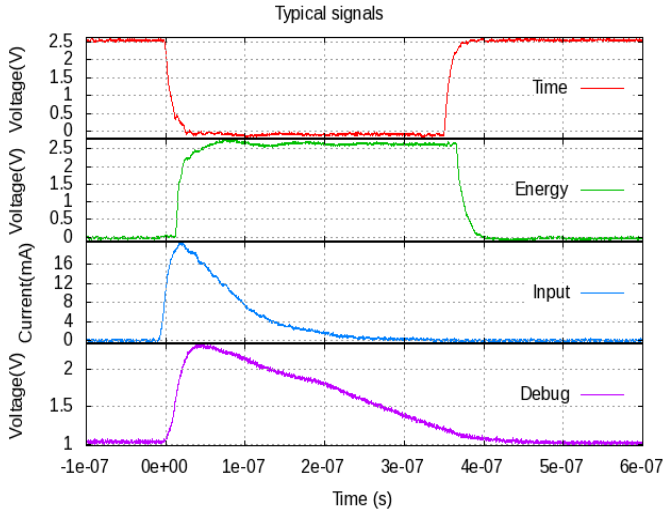
- Joint project with CIEMAT to develop a time-over-threshold ASIC for SiPM based PET
  - ICCUB: electronics and microelectronics design
  - CIEMAT: PET and medical imaging instrumentation

- Optimized for segmented crystals with adjustable dynamic range



FlexToT

16 channel
SiGe BiCMOS 0.35um austriamicrosystem
10 mm^2
3.3 V (10 mW/ch)
QFN 64



The FlexToT ASIC

- FlexToT ASIC main features (I)
  - linear time-over-threshold (ToT) design
    - output signal width proportional to input current peak value
  - 16 input analog channels (current)
  - 16 digital ToT output channels (energy)
  - 1 fast CML trigger output (time)
  - current amplifiers with DC coupling for low input impedance (34 Ω) and 250 MHz bandwidth (**> 400 MHz for FlexToT v2**)
  - bias voltage of each SiPM pixel individually adjustable for correcting temperature and gain variations
  - magnetic field (MR) tolerant

The FlexToT ASIC

- FlexToT ASIC main features (II)
  - low power consumption of ~10 mW/channel
  - sub-nanosecond timing with a trigger jitter better than 30 ps (**< 10 ps for FlexToT v2**) limited by measuring system
  - simple readout by an FPGA including a time-to-digital conversion (TDC)
  - linearity better than 5% for a dynamic range in current peak values from 0.7 mA to 18 mA (55 pC to 2 nC input charge)
  - internal gain saturation control and pile-up detection
  - fabricated by AMS (Austria) in 0.35 µm HBT BiCMOS technology
    - die size 2.93 mm x 2.54 mm, mounted on a 9 mm x 9 mm QFN64 package

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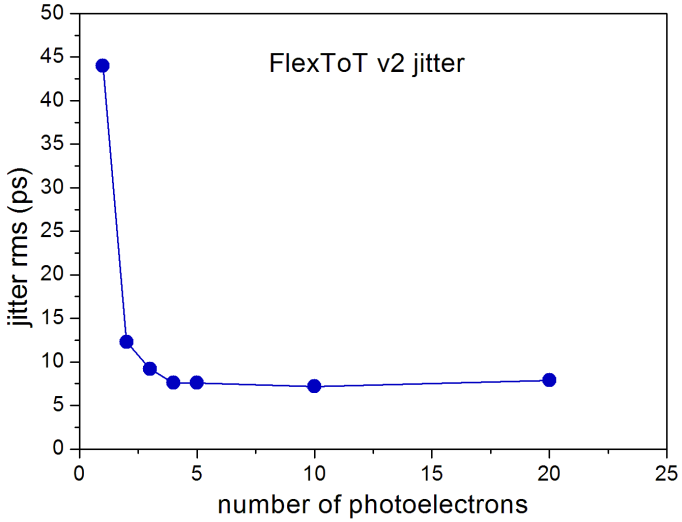
FlexToT v2 jitter measurements

- Time difference between calibration input signal and ASIC trigger
  - Measurement setup:
    - Agilent 81110A (330 MHz) pulse generator
    - 4 GHz / 20 GSPs DPO scope
    - Threshold set to detect 1 photon equivalent



- Jitter better than **8 ps (rms)** for signals larger than 3 photoelectrons
- Best result: **7.2 ps (rms)** for ~10 photoelectrons signal

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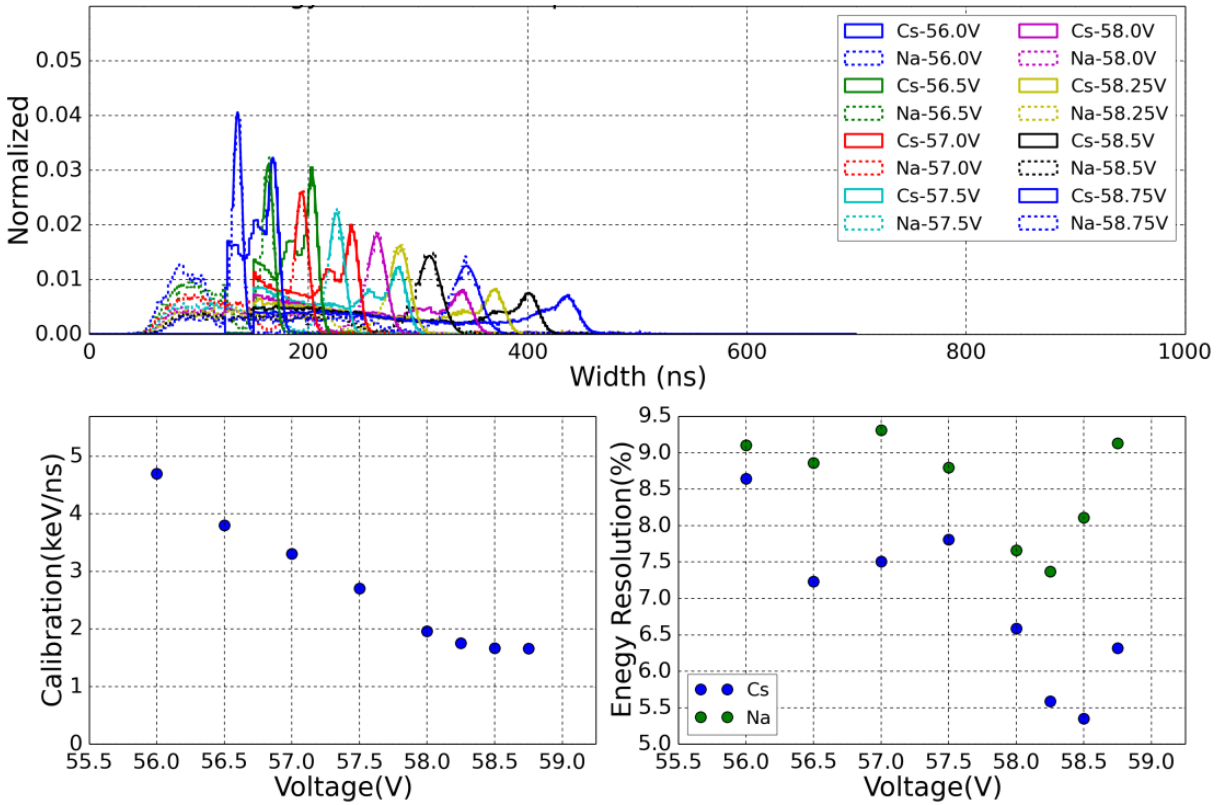
Energy Resolution: pixelated

- Energy resolution using Cs 137 and Na 22 for calibration: < 8 %
  - 20x3x3 mm^3 LFS crystals
  - HPKK 3x3 mm^2 - 50 um sensors

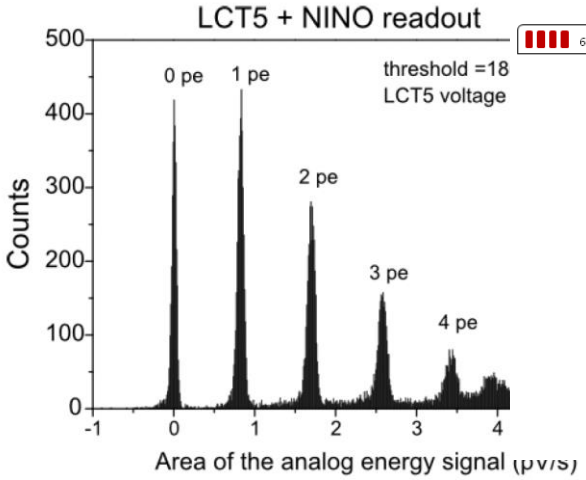


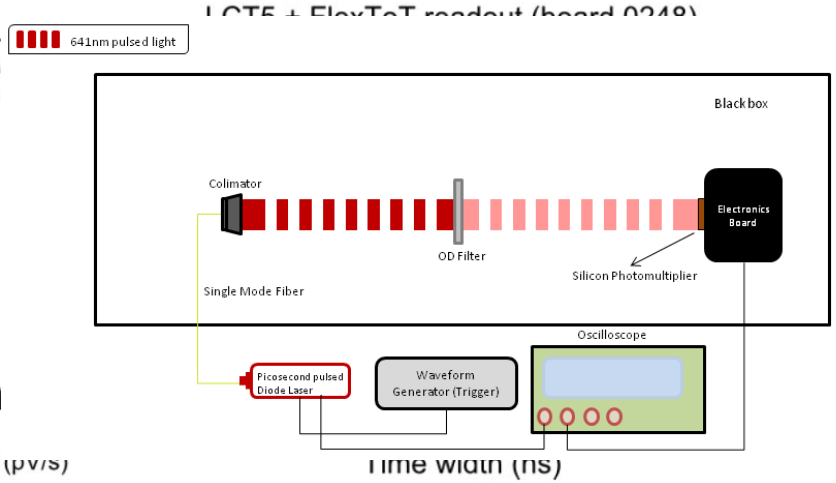
The FlexToT ASIC

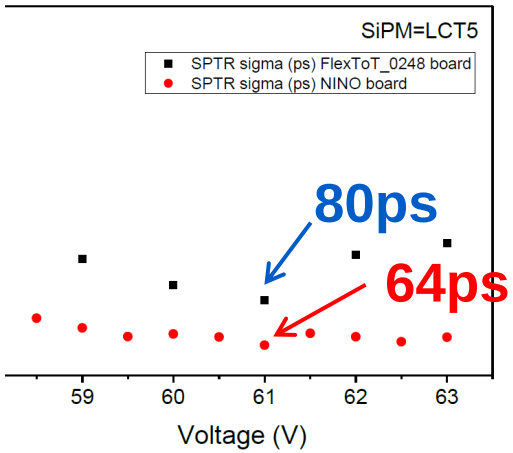
- The timing performance of the FlexToT v2 ASIC was measured at CERN and compared with NINO readout electronics
  - STSM of Iciar Sarasola (CIEMAT), COST Action TD1401 “FAST”
- A portable setup with two FlexToT readout cards was carried to CERN during August 2015 to evaluate:
  - Single Photon Timing Resolution (SPTR)
  - Coincidence Time Resolution (CTR)
- Measurements were performed using both NINO and FlexToT readout electronics under similar operational conditions

FlexToT v2 timing measurements at CERN

- Single Photon Time Resolution (SPTR)
  - Pilas picosecond laser at 420 nm, 28 ps (FWHM) pulses at 100 kHz rate
  - LeCroy WaveRunner 104 Xi 1 GHz oscilloscope (10 Gs/s)
  - Laser intensity reduced by neutral density (ND) filters
  - Measurements performed in a light-tight box at 18.5 °C
  - Hamamatsu S13360-3050CS (LCT5) 3x3 mm^2 MPPC



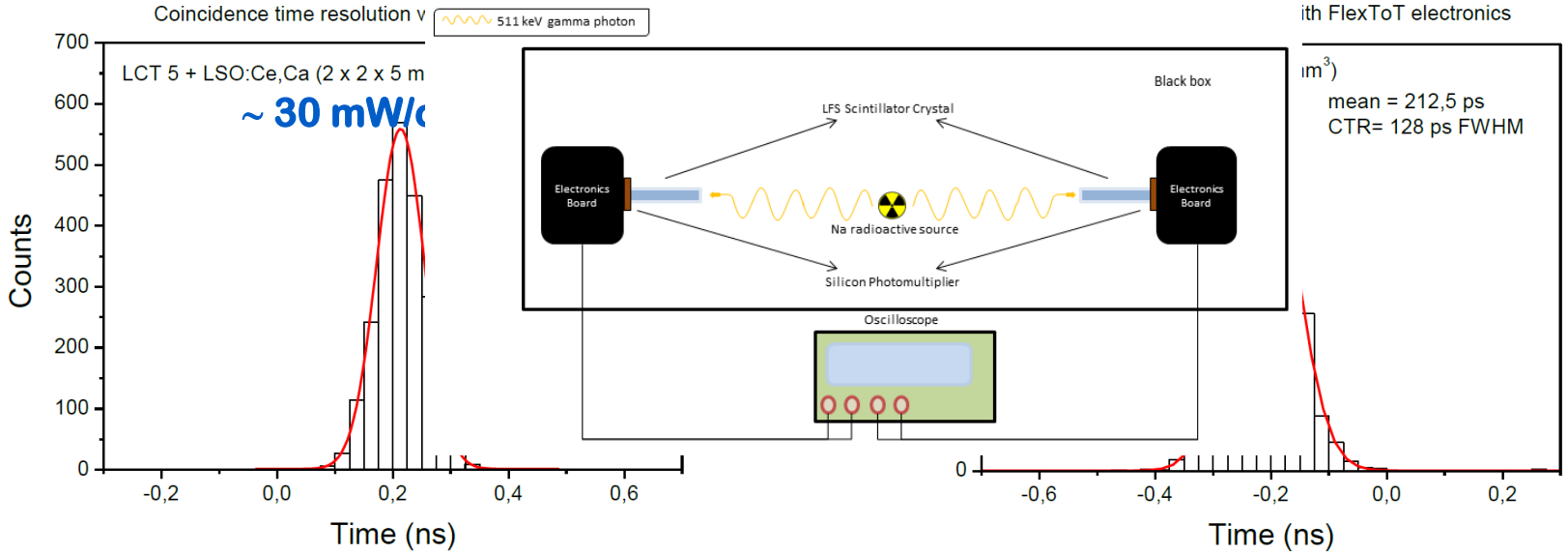




- Best results (sigma): **64** ps for NINO and **80** ps for FlexToT

FlexToT v2 timing measurements at CERN

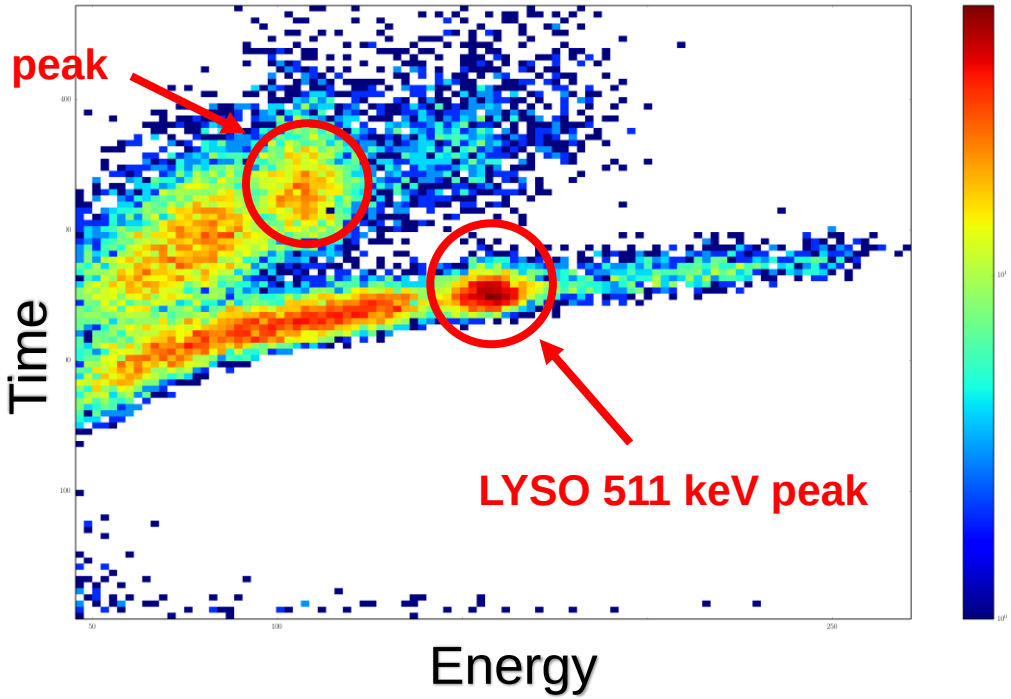
- Coincidence Time Resolution (CTR)
  - 2x2x5 mm^3 LSO:Ce,Ca crystals on Hamamatsu S13360-3050CS (LCT5) 3x3 mm^2 MPPCs
  - LeCroy DDA 735Zi-A 3.5 GHz Analyzer (40 Gs/s)
  - Measurements performed in a light-tight box at 15 °C
  - Coincidences corresponding to 511 keV photopeak (+/- 3 sigma) in both detectors



•Best results (FWHM): **97 ps** for **NINO** and **128 ps** for **FlexToT** readout

DOI in phoswich configuration

- The FlexToT allows time discrimination from two type of crystals with different decay times.



- MPPC array S12572, 4x4 with 3x3mm^2/ch with 50um
- Stack configuration: GSO and LYSO, 1.35x1.35mm^2 with 7mm and 8mm long respectively.

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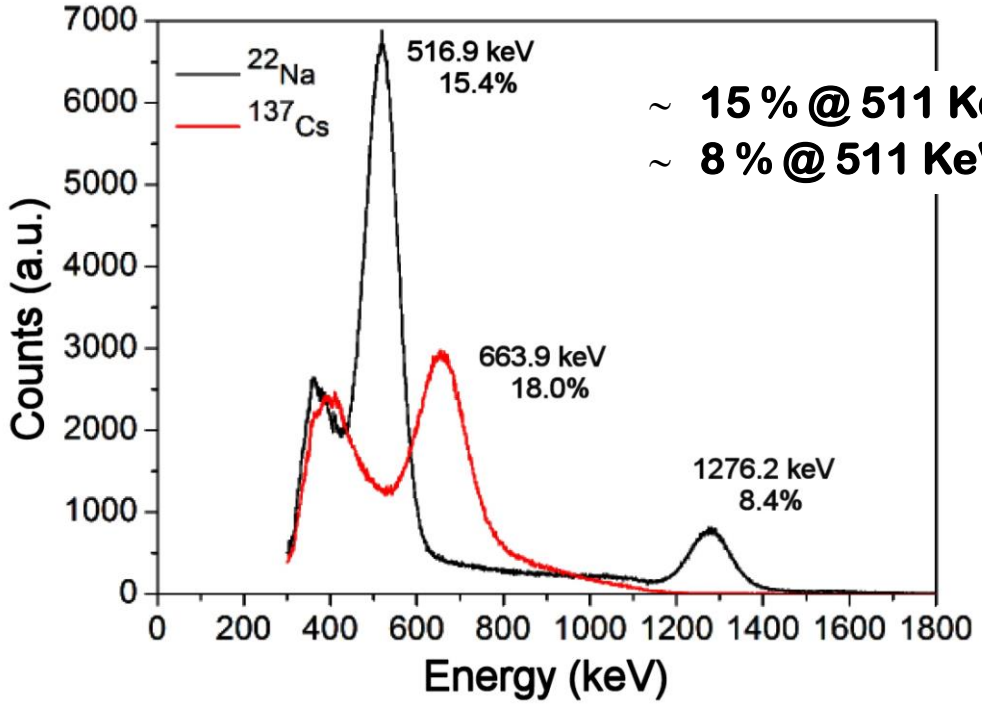
Energy Resolution: monolithic

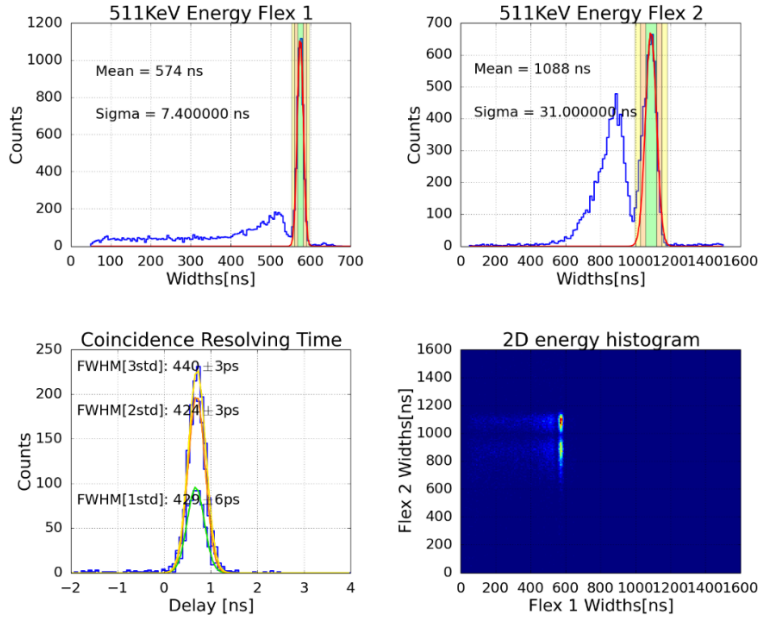
- Energy resolution and linearity with LYSO monolithic scintillator blocks
  - Resolution at 511 keV: 15.4% FWHM
  - Linearity (511-662-1274 keV): $R^2 = 0.99975$
    - Raw spectra obtained by summing the ToT outputs of all channels

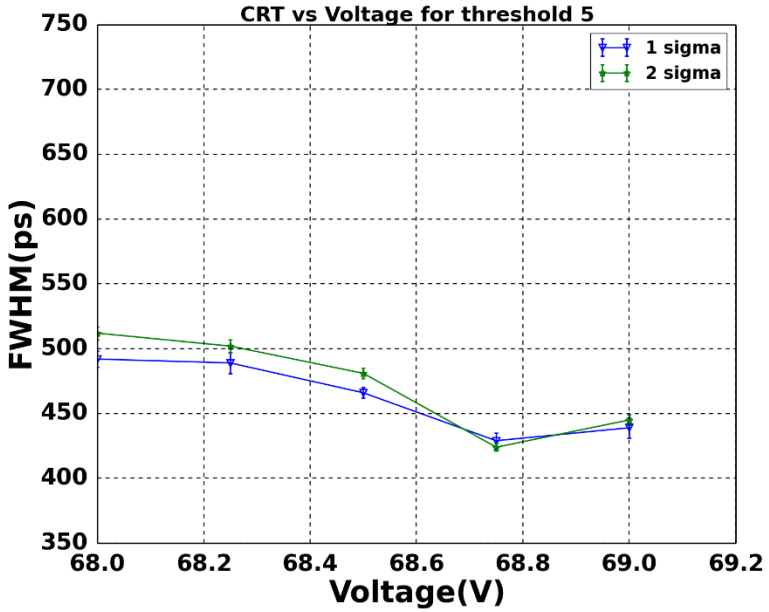


~ 15 % @ 511 KeV (monolithic)

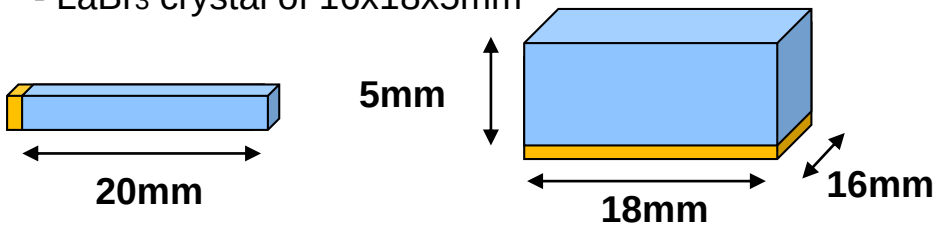
~ 8 % @ 511 KeV (segmented)

BEST CTR with large $LaBr_3$ crystal





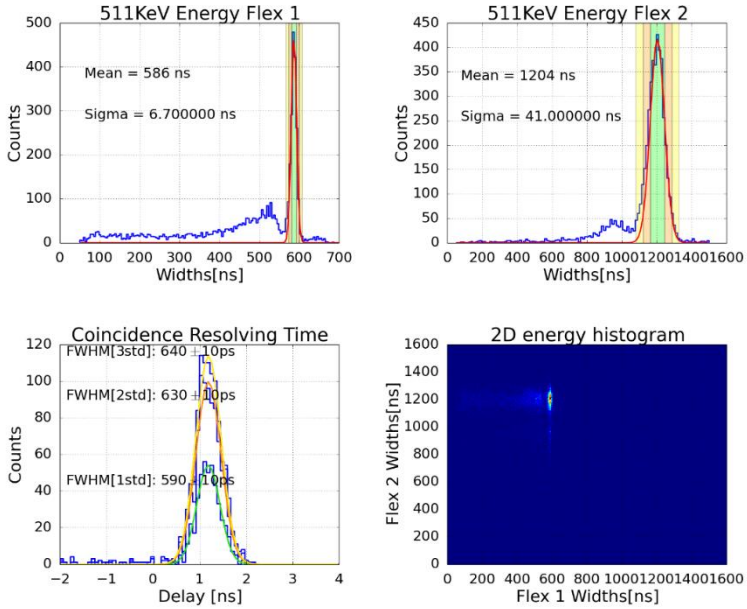
- MPPC array S12572, 4x4 with 3x3m/ch with 50um
- $LaBr_3$ crystal of $16x18x5mm^3$

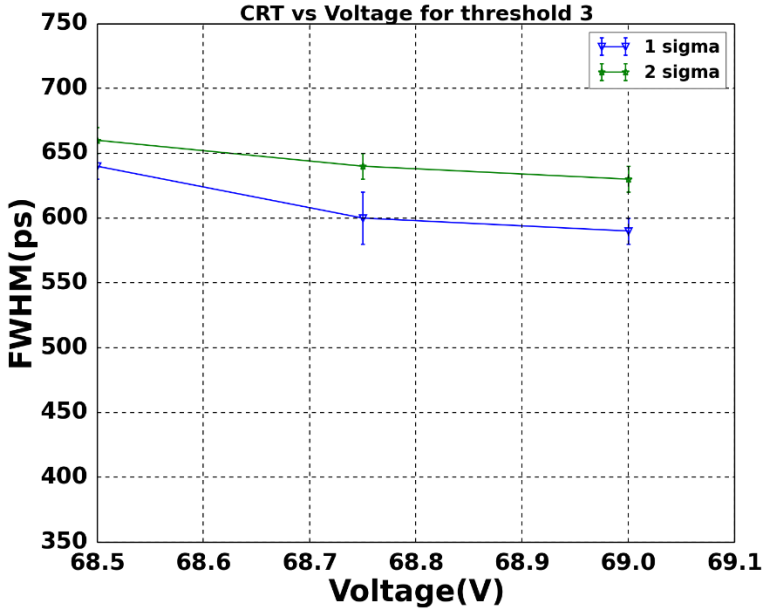


•MPPC array with monolithic $LaBr_3$ in coincidence with single channel MPPC.

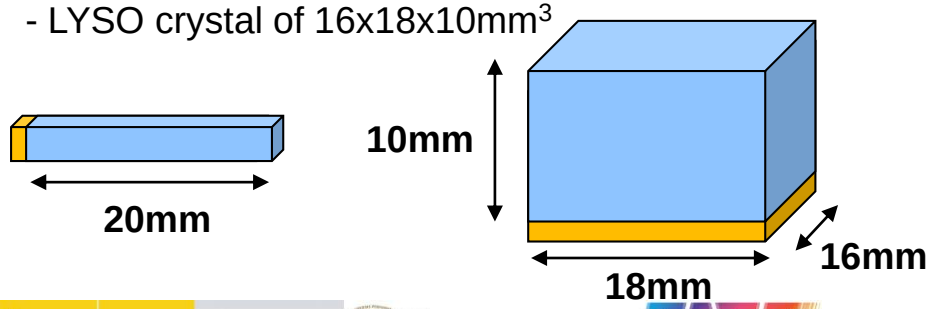
•CTR < 450ps

BEST CTR with large LYSO crystal





- MPPC array S12572, 4x4 with 3x3mm^2/ch with 50um
- LYSO crystal of 16x18x10mm^3



•MPPC array with monolithic LYSO in coincidence with single channel MPPC.

•CTR < 650ps

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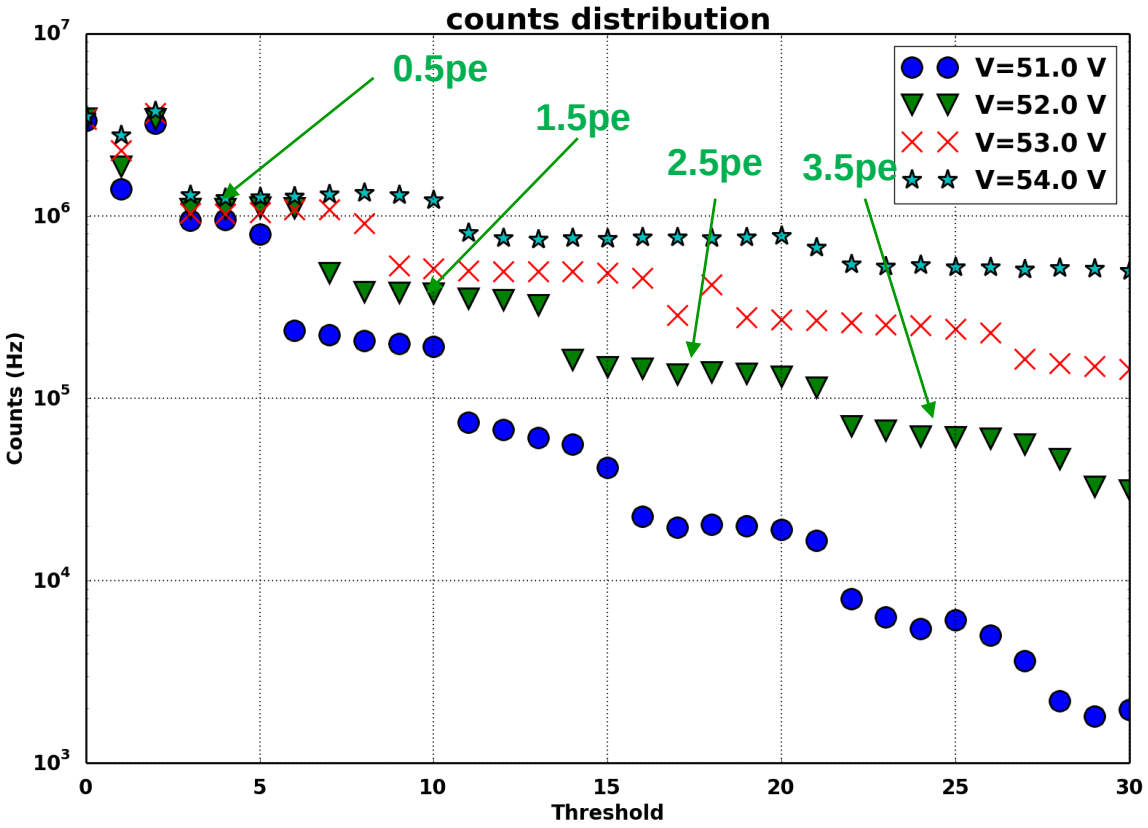
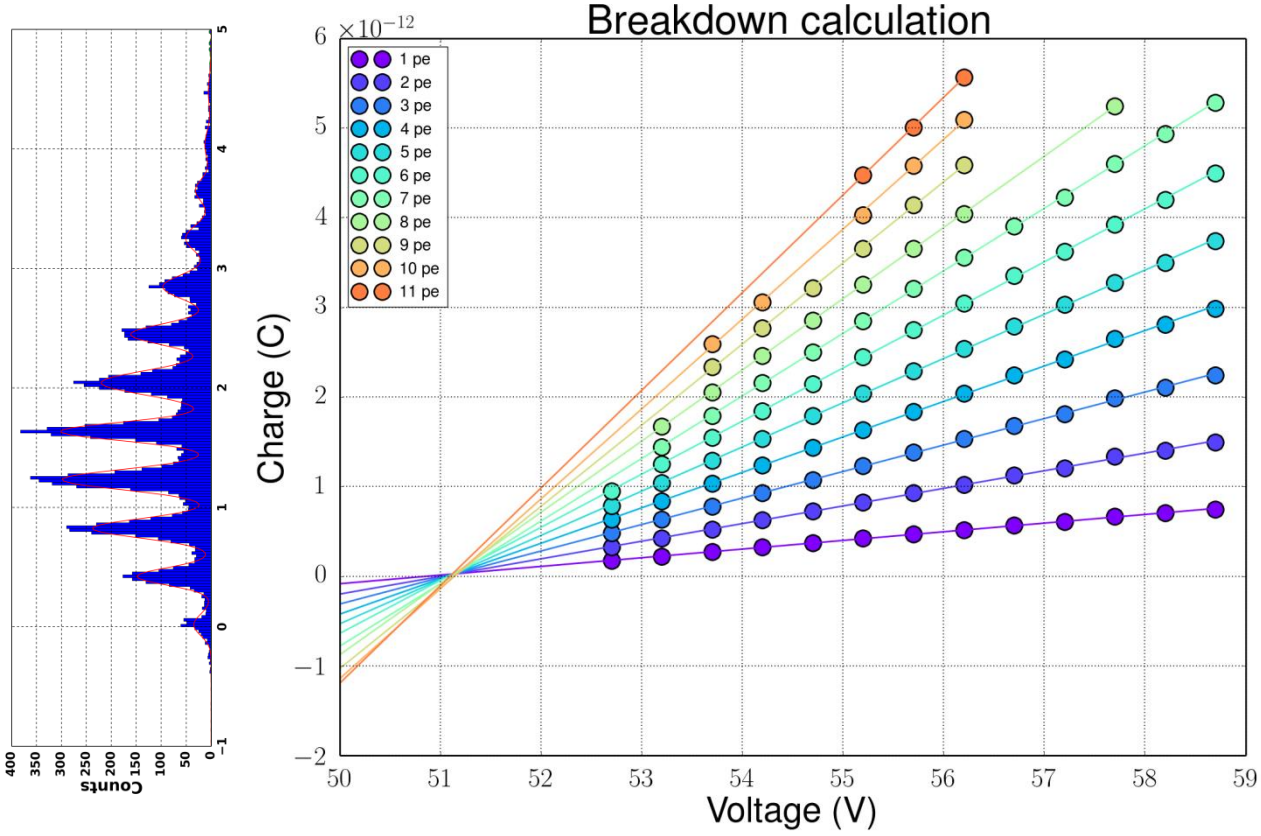
MPPC characterization: DCR



- MPPC LCT2-50um
- Number of pulses on a 10μs windows

MPPC characterization using PACTA



- MPPC single channel S13360, 6x6mm²/ch with 50um
- Picosecond (50 ps FWHM) laser

- Breakdown voltage 51.2V

Summary and conclusions

- UB and CIEMAT have designed and implemented an ASIC for the readout of SiPMs coupled to scintillators in (TOF)PET applications
  - Good linearity (better than 5%) from 0.7 mA to >18 mA peak input current (FlexToT v2)
  - Jitter better than 8 ps for signals larger than 3 photoelectrons

- Good results in SPTR, CTR and DOI capability:
  - 80 ps σ for single photoelectron timing resolution
  - 128 ps FWHM coincidence time resolution with LSO:Ce,Ca scintillators (FlexToT v2)
  - DOI discrimination with stacked GSO + LYSO crystals
  - <450 ps FWHM coincidence time resolution with $LaBr_3$ and <650 ps FWHM for LYSO monolithic crystals (FlexToT v2)

- PACTA really works for MPPC characterization

FUTURE STEPS

- Detailed PENELOPE simulations.
- New ASIC version for monolithic crystal (180nm CMOS, 3.5 mW/ch)
- DOI corrections and channel equalization.
- Optimization of MR-compatible demonstrator with 64 channel DAQ board.

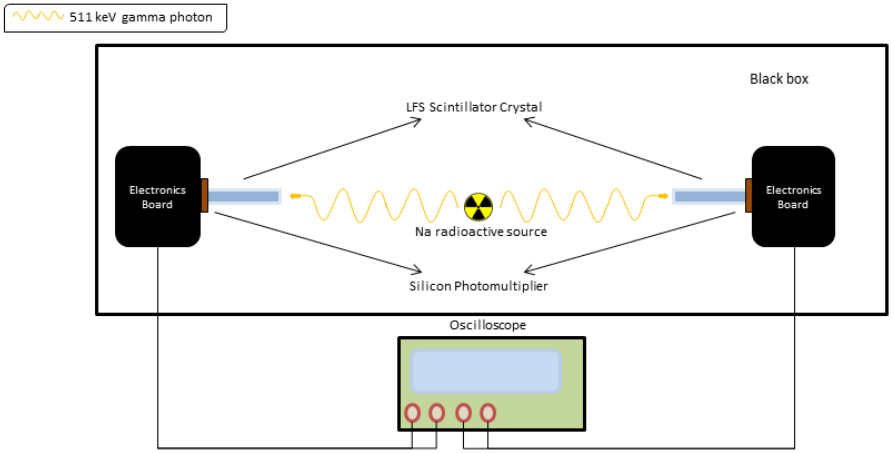
Acknowledgements

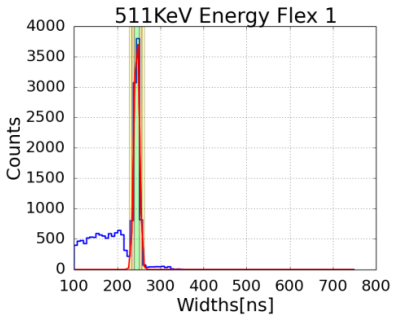
- **Fast**
- **MEDAMI organizers**
- **Hamamatsu**

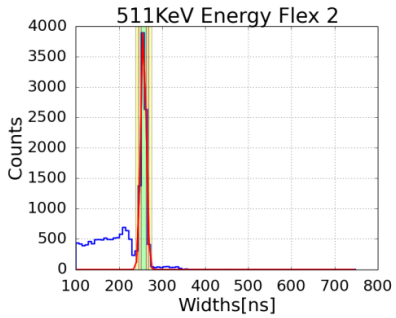
Thanks for your attention!

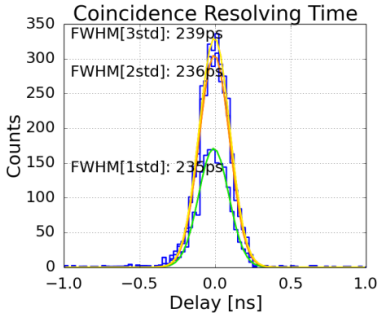
FlexToT Time Properties: CTR

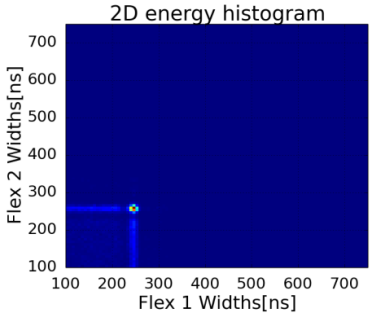
- Coincidence time resolution measurements for
- Classical photopeak selection
  - Results @ ±2σ
  - 20x3x3 mm^3 LFS crystals
  - LCT4 3x3mm 50um

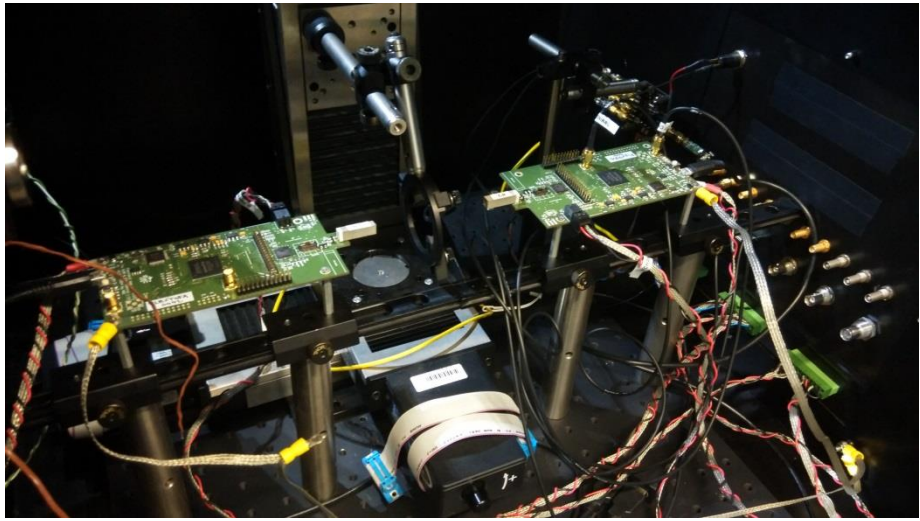




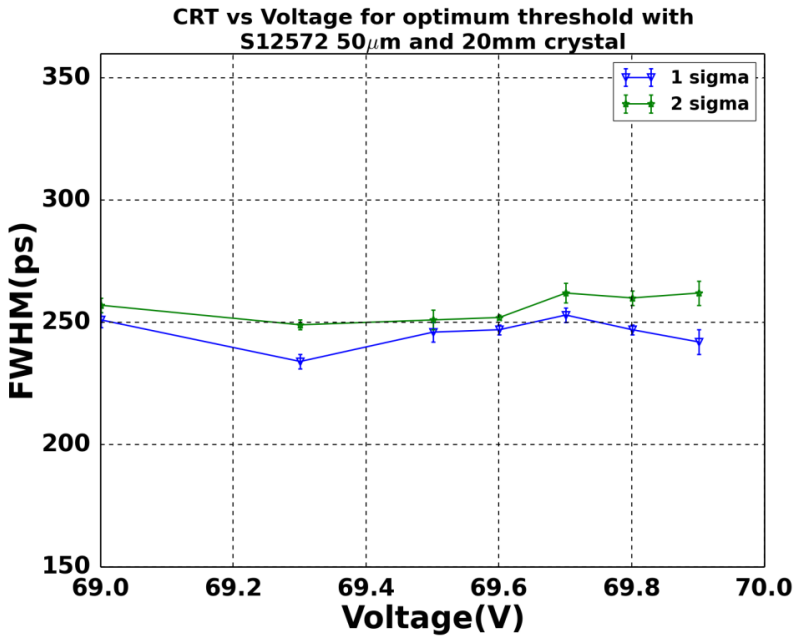


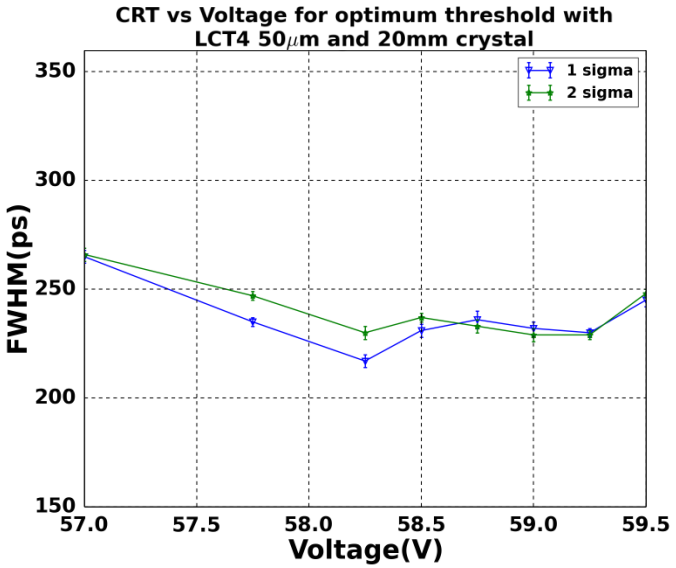


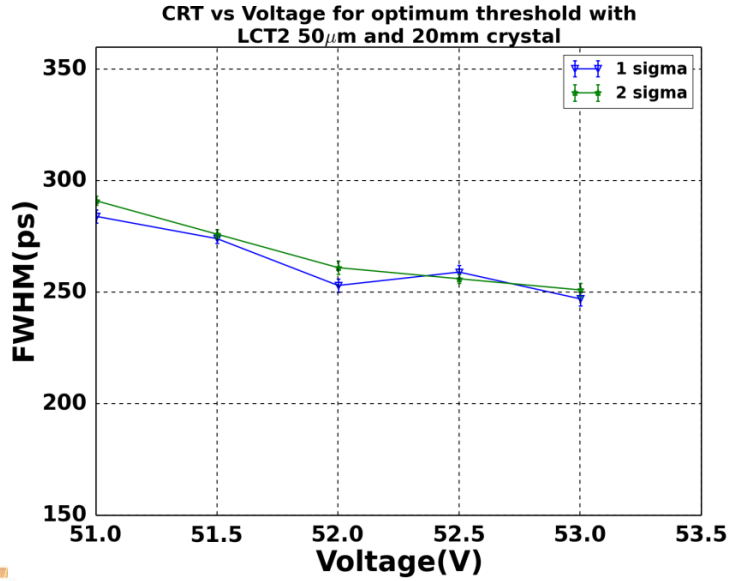




FlexToT Time Properties: CTR



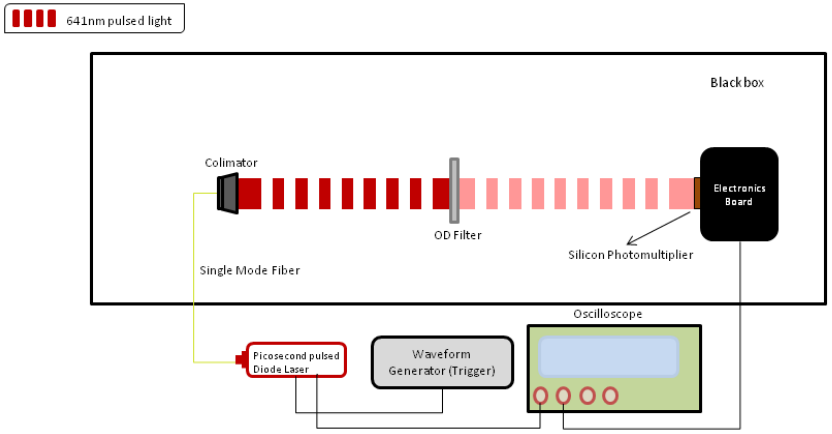


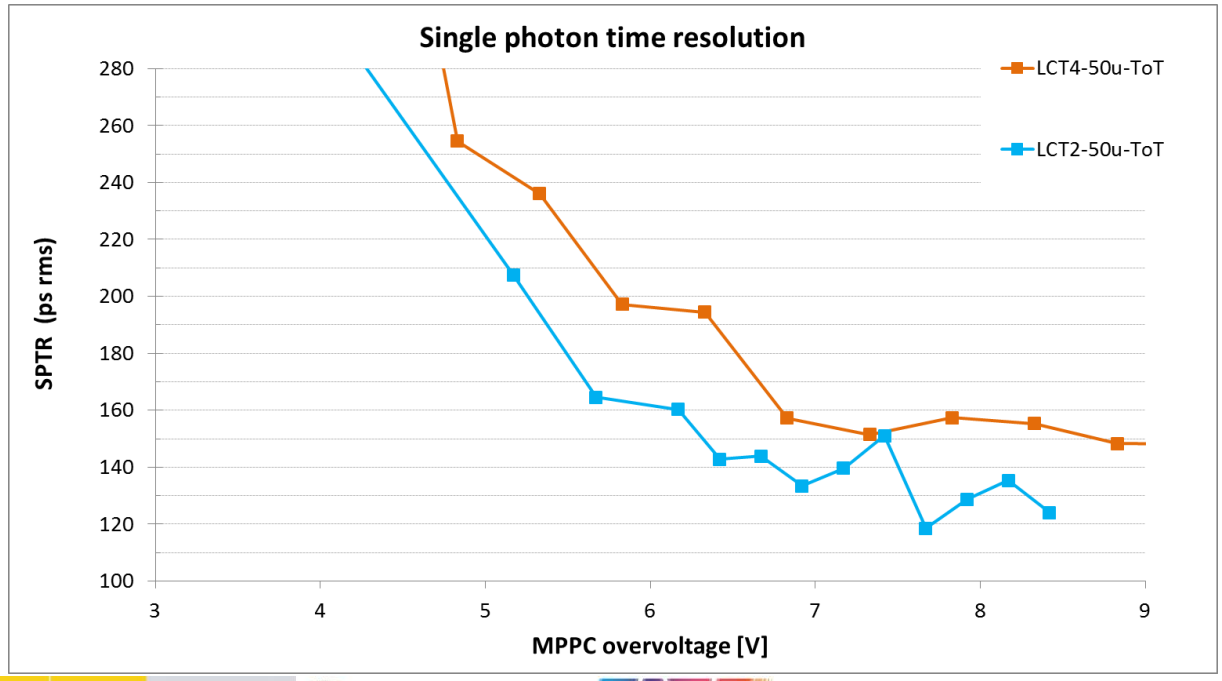


- CTR results with 20mm crystals:
  - S12572 ~ 250ps FHWM
  - LCT2 ~ 260ps FHWM
  - LCT4 ~ 220ps FHWM

FlexToT Time Properties: SPTR

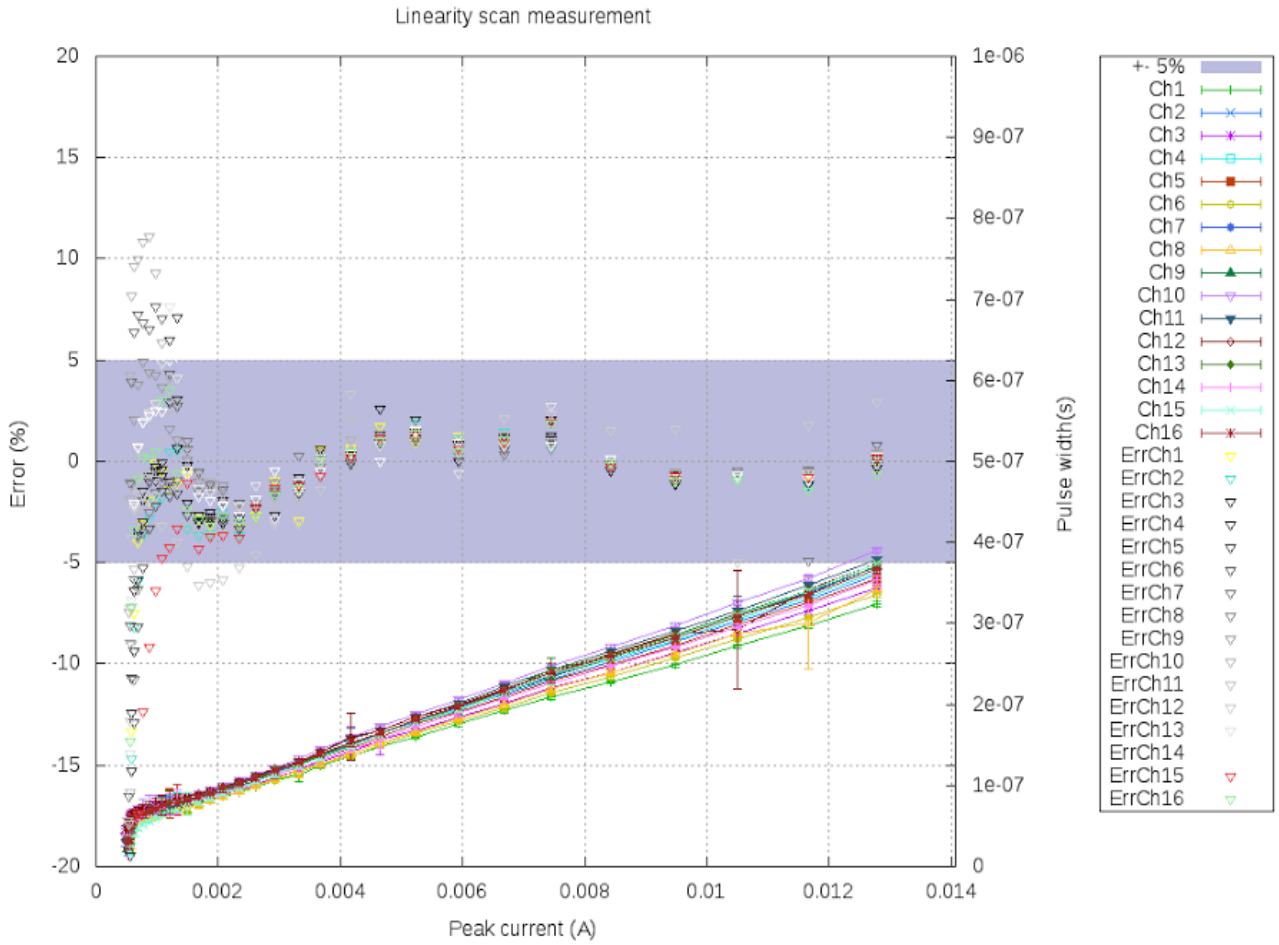
- Single Photon Time Resolution
  - Picosecond (50 ps FWHM) laser
- Jitter floor < 10 ps rms
  - For very large signals



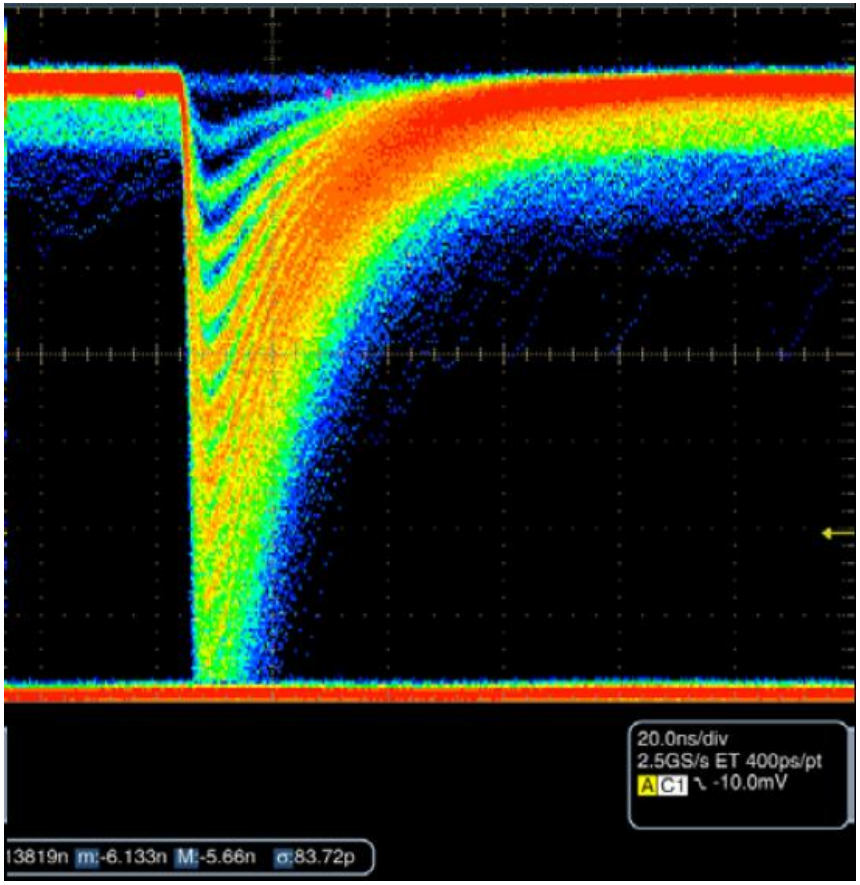


•FlexToT ASIC

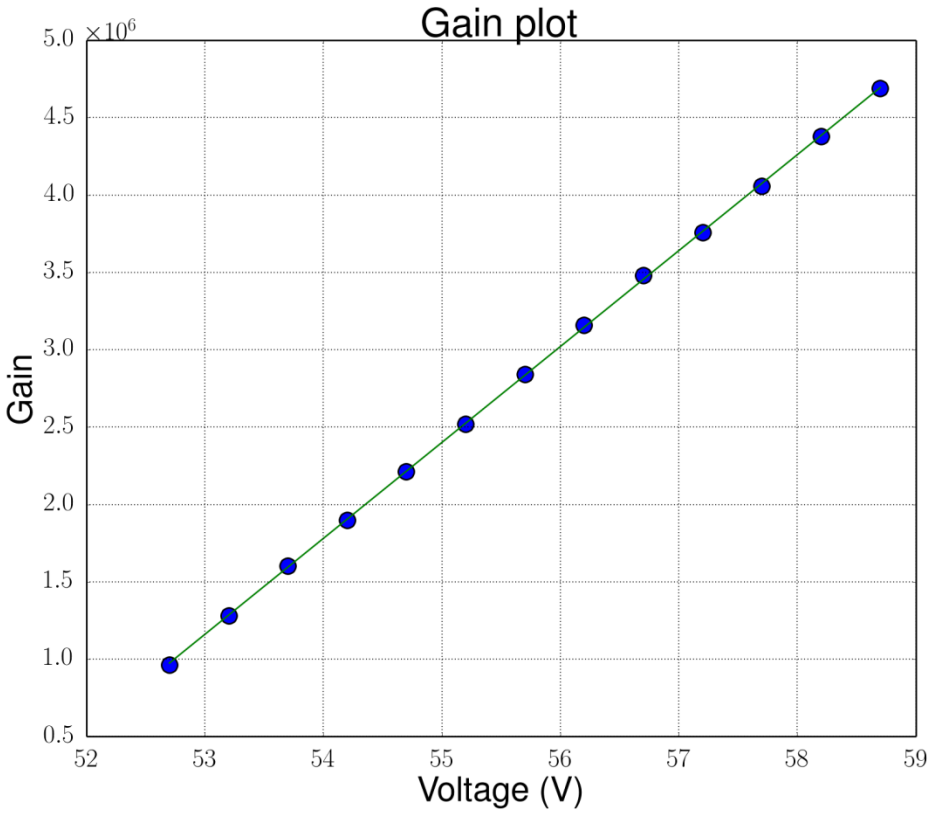
- Good linearity and uniformity
  - With only comparator threshold offset equalization
- Different operating ranges can be covered



MPPC characterization photon distribution charge



MPPC characterization gain plot



MPPC characterization Vb and Cd+Cq