Università degli Studi di Milano

INFN Istituto Nazionale di Fisica Nucleare

$LaBr_3$:Ce detectors, phototubes, electronics and signal processing: hands-on report about on-going research

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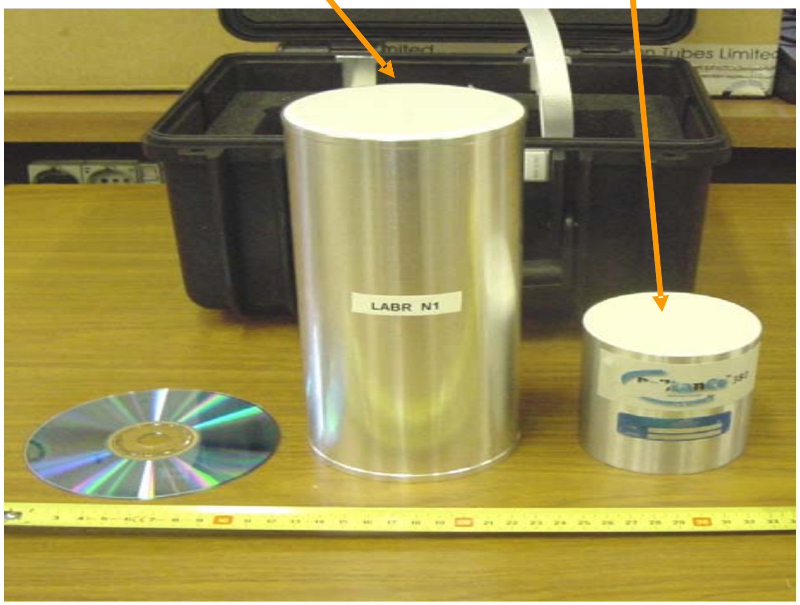
14-16 November 2011

$LaBr_3$:Ce detectors for Nuclear Physics

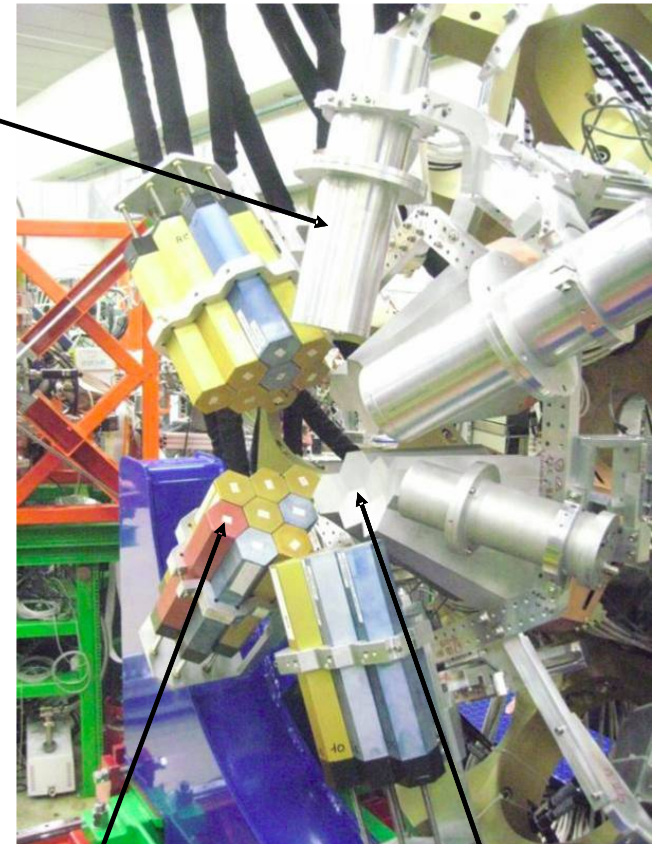
Ø 3.5” x 8”

Ø 3” x 3”



Encapsulated crystals (by Saint Gobain)

$LaBr_3$ scintillators



BaF_2 scintillators

HPGe detectors

Experimental set-up for GQR measurement at the Legnaro National Laboratory - INFN

Ten detectors (Ø 3.5” x 8”) in Milano,
already used for experiments in Legnaro, GSI, Riken, Debrecen.

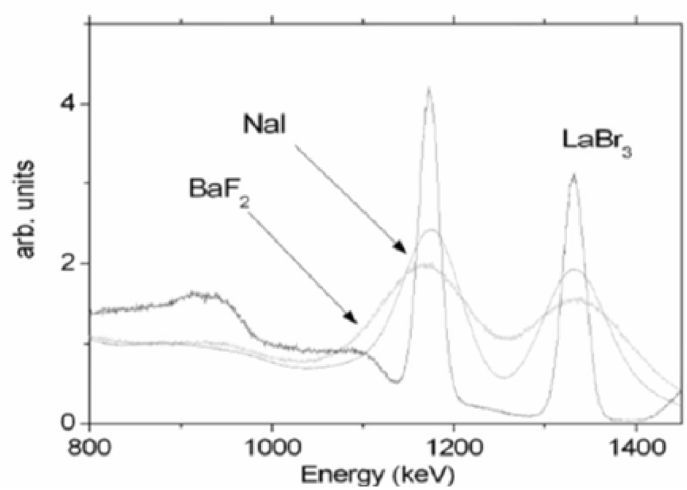
$LaBr_3$:Ce detectors for Nuclear Physics

Scintillator	Light Yield (photons/keV)	1/e Decay time t (ns)	F.O.M $\sqrt{\frac{t}{LY}}$	Wavelenght of maximum emission $\lambda m(nm)$	Refractive Index at λm	Density (g/cm^3)	Thickness (cm) for 50% attenuation (662keV)
NaI(TI)	38	250	2.6	415	1.85	3.67	2.5
BrilLanCe™ 350	49	28	0.8	350	1.9	3.85	2.3
BrilLanCe™ 380	63	16	0.5	380	1.9	5.08	1.8
BaF_2	1.8	0.7	0.6	~210	1.54	4.88	1.9
PreLude™ 420	32	41	1.1	420	1.81	7.1	1.1
BGO	9	300	5.8	480	2.15	7.13	1.0

- High light yield (1 MeV → 63,000 photons): good energy resolution (2.9% @ 661 keV)
- Fast photons emission (16 ns decay time): good time resolution (300 ps rms @ 661 keV)
- High detection efficiency and large crystals available
- Easiness of operation (room temperature, no cryostat, nor vacuum technology)
- High hygroscopicity (crystals partially sealed in aluminum enclosure)
- Internal radioactivity (e.g. 1435 keV, 0.02 Bq/cc; ≈2000 cps in total for Ø 3.5” x 8” detectors)

Front-end electronics for $LaBr_3$:Ce detectors

	HPGe	BaF_2	$LaBr_3$:Ce
Energy resolution (FWHM) @ Co^{60} 1332 keV line	< 0.2%	< 9%	< 2.5%
Time resolution (FWHM) @ Co^{60} 1332 keV line	< 10 ns	< 0.5 ns	< 1 ns
Most appropriate read-out electronics	Charge Sensitive Preamplifier	Fast PMT + Voltage Amplifier	???

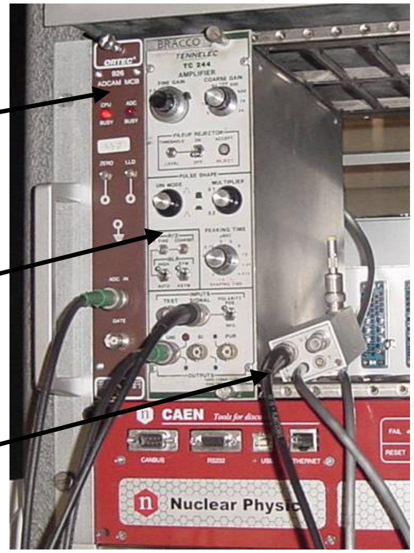


Interested in energy

Interested in time

Electronics currently in use in Milano

Commercial electronics
for HPGe detectors



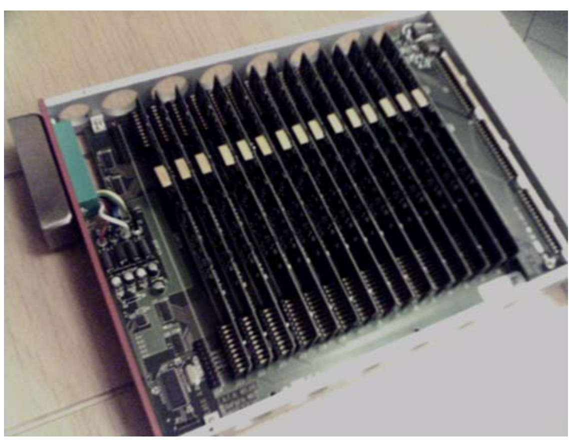
Multi-channel analyzer

Shaping amplifier

Charge sensitive preamplifier

- Electronics does not degrade energy resolution
- Time information is lost
- Saturation effects might appear on CSPs or shaping amplifier (if no CPS is used), due to delta-like shape of signals
- Bulky and expensive for many detectors

BaFPro: 16 channels NIM module developed in Milano



- Designed for BaF_2 scintillators (no CSP)
- Good time information (CFD, < 100 ps rms)
- Pulse Shape Discrimination (fast vs slow)
- Improved for $LaBr_3$:Ce scintillators:
  no saturation up to 40 MeV
  but still energy resolution is somehow degraded under 1 MeV

New electronics for $LaBr_3$:Ce detectors

Big investment in money to buy detectors

⇩

Optimize electronics and signal processing

- Acquisition and analyses of signals (noise, non-linearity, etc.)
- Study and simulation of electronics and algorithms (voltage divider, DAQ, etc.)
- Design and manufacturing of electronics
- In depth testing (also at experimental facilities)

<u>Status at 2011 Q3</u>

- Photo-multiplier tube → tested, ok
- Voltage divider network → tested, ok
- Readout and control electronics → designed
- Digital acquisition system → simulated, design in progress
- Processing algorithms → simulated (experimental signals)

Photo-multiplier tube

Energy estimation:
- spatial uniformity of conversion gain (light to output current) over the entire photo-cathode
- good internal structure for linearity (e.g. no “venetian blinds”)
- low noise

Time estimation:
- spatial uniformity of electrons transit time from the whole entire photo-cathode towards 1st dynode
- fast single photon response (short rise and fall times)

Large area detector:
- Ø 3.5” flat window to match the detector and to collect all emitted photons

These requirements are difficult to match at the same time so PMT choice is a compromise

Our selection (not so many manufacturing companies, either)

Hamamatsu R6233-100-SEL

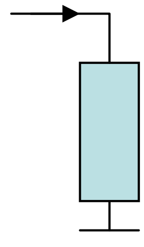
(8 dynodes; gain = 230,000 @ 1000V, with supplied voltage divider)

Time measurements

Detector

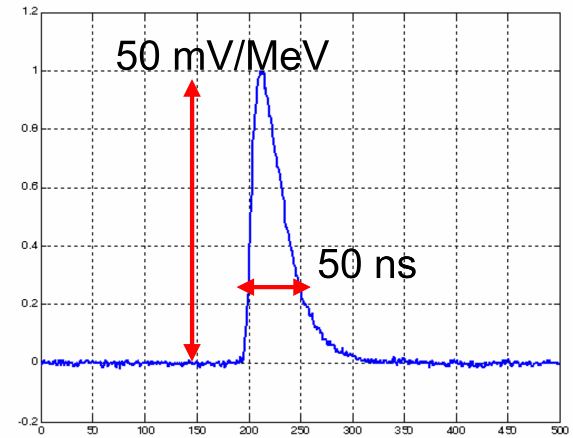
+

R6233-100-SEL (Ø 76 mm)

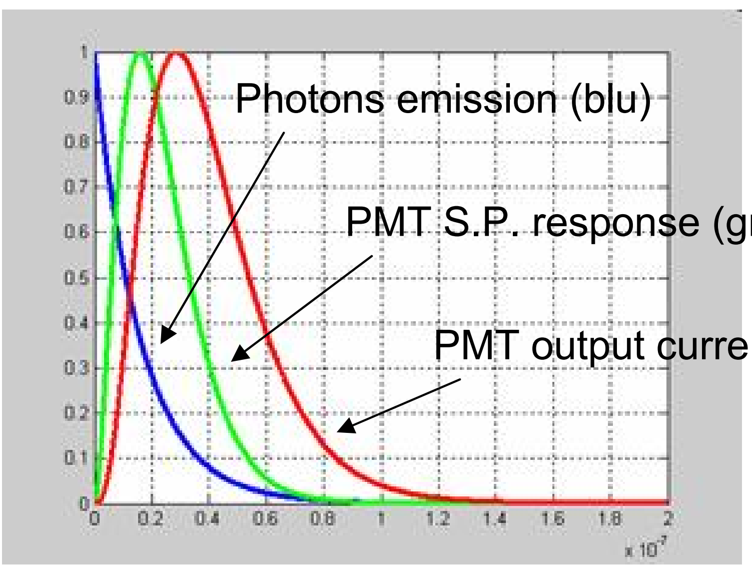


50 Ohm

=



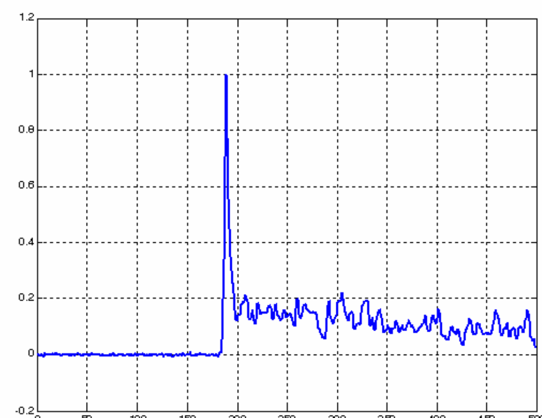
PMT output signal (50 Ohm load)



Simulation of PMT output signal

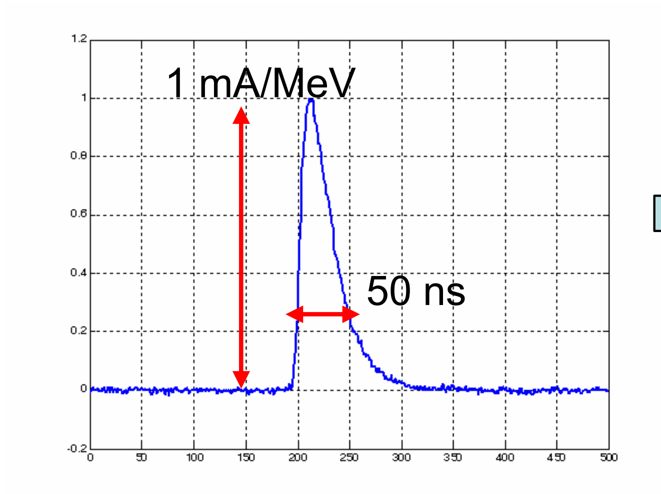
Time resolution limited by:

- Increased rise and fall time
- Multiple reflections of photons inside detector



BaF_2 fast PMT output signal (50 Ohm load)

Energy measurements



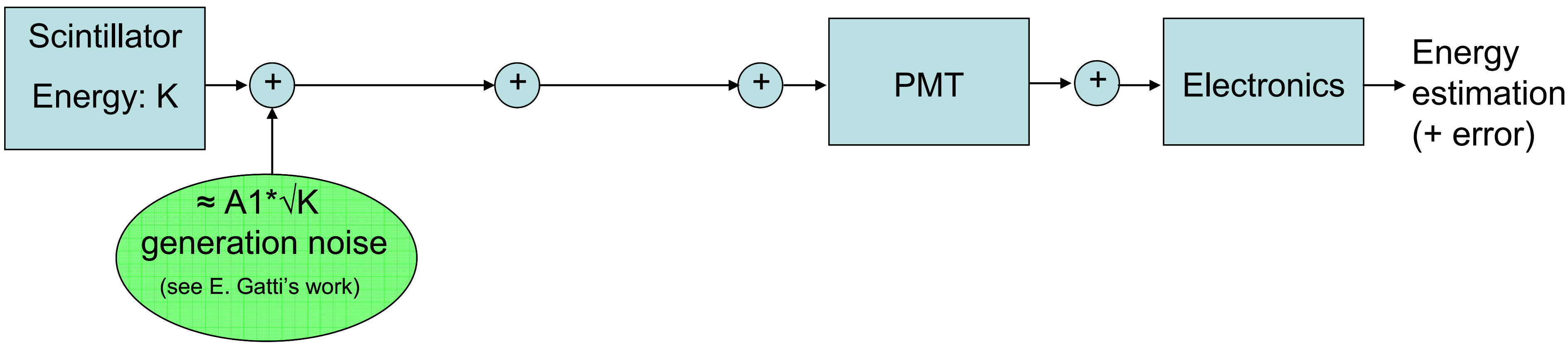
PMT output signal (50 Ohm load)

Q ≈ 20 pC/MeV

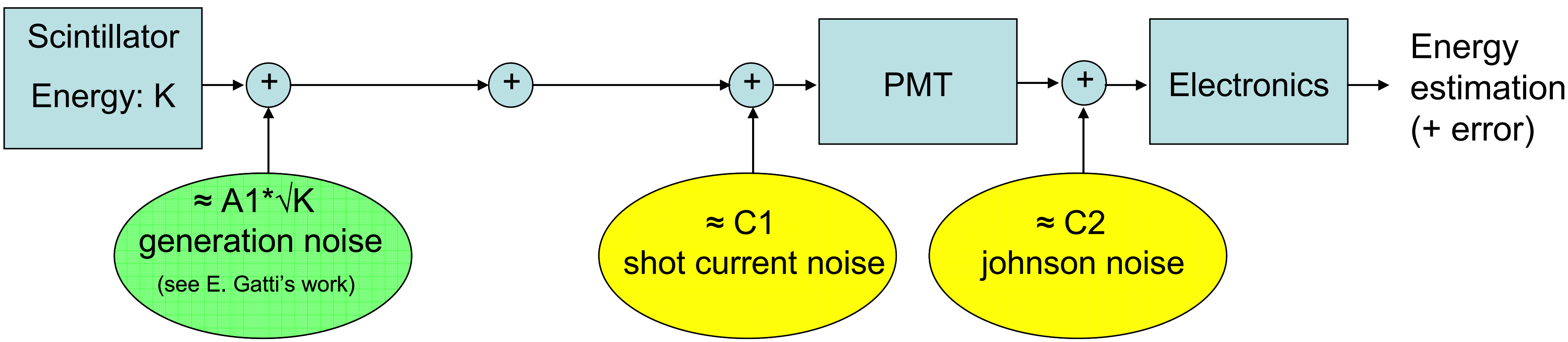
(huge signal, easily processed by CSP;
as reference, 54 fC/MeV for HPGe;
but for high counting rate, P/Z compensation is critical)

- Output signal of CSP (attached to voltage divider) still available for analog processing
- Digital processing only based on direct current PMT output signal (very low noise, high frequency front-end electronics is required)
- Large crystals may be relatively non homogeneous in doping distribution (one of the fundamental factors limiting the energy resolution)

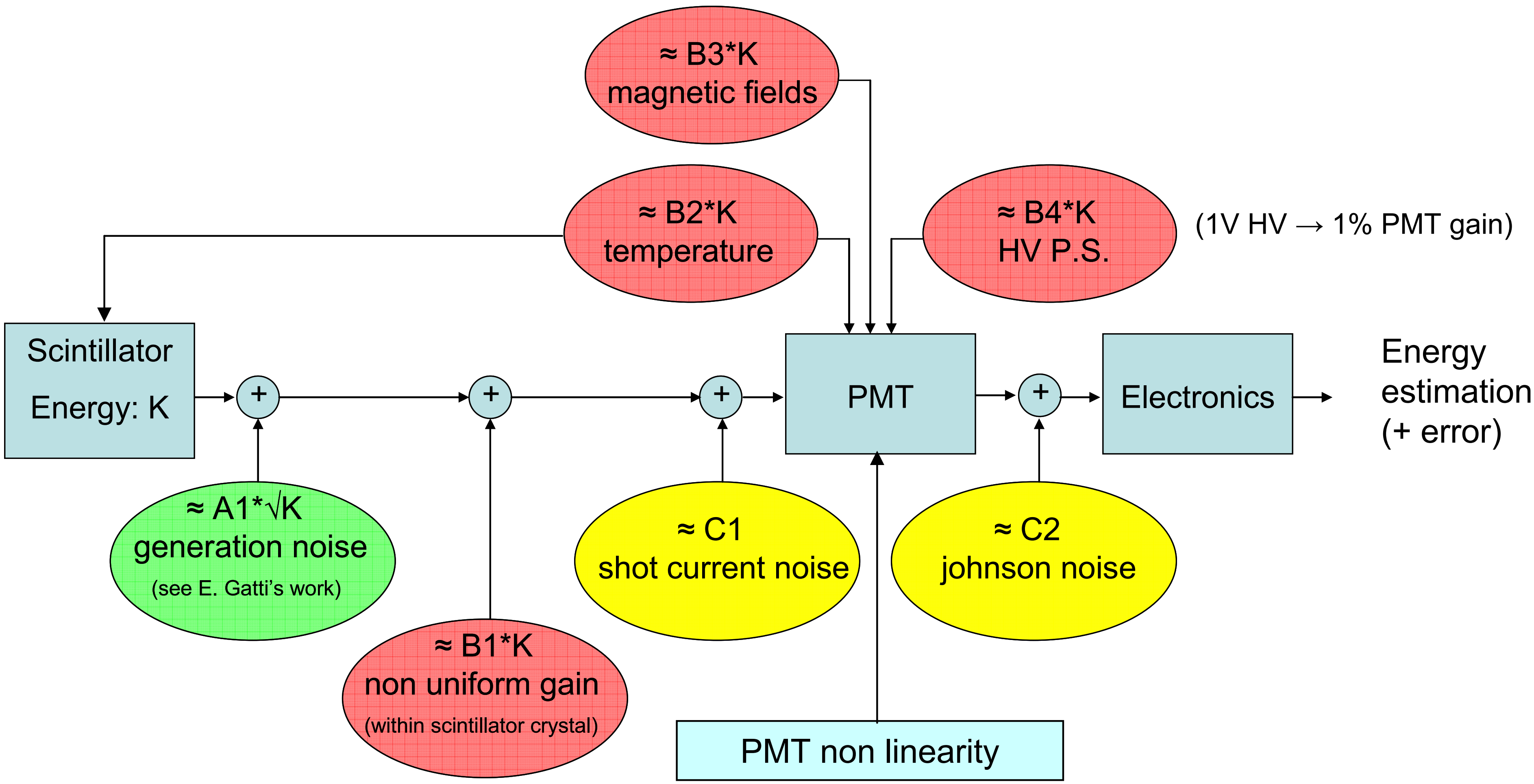
Effects limiting energy measurements



Effects limiting energy measurements



Effects limiting energy measurements



Important contribution
- at low energy: C1, C2

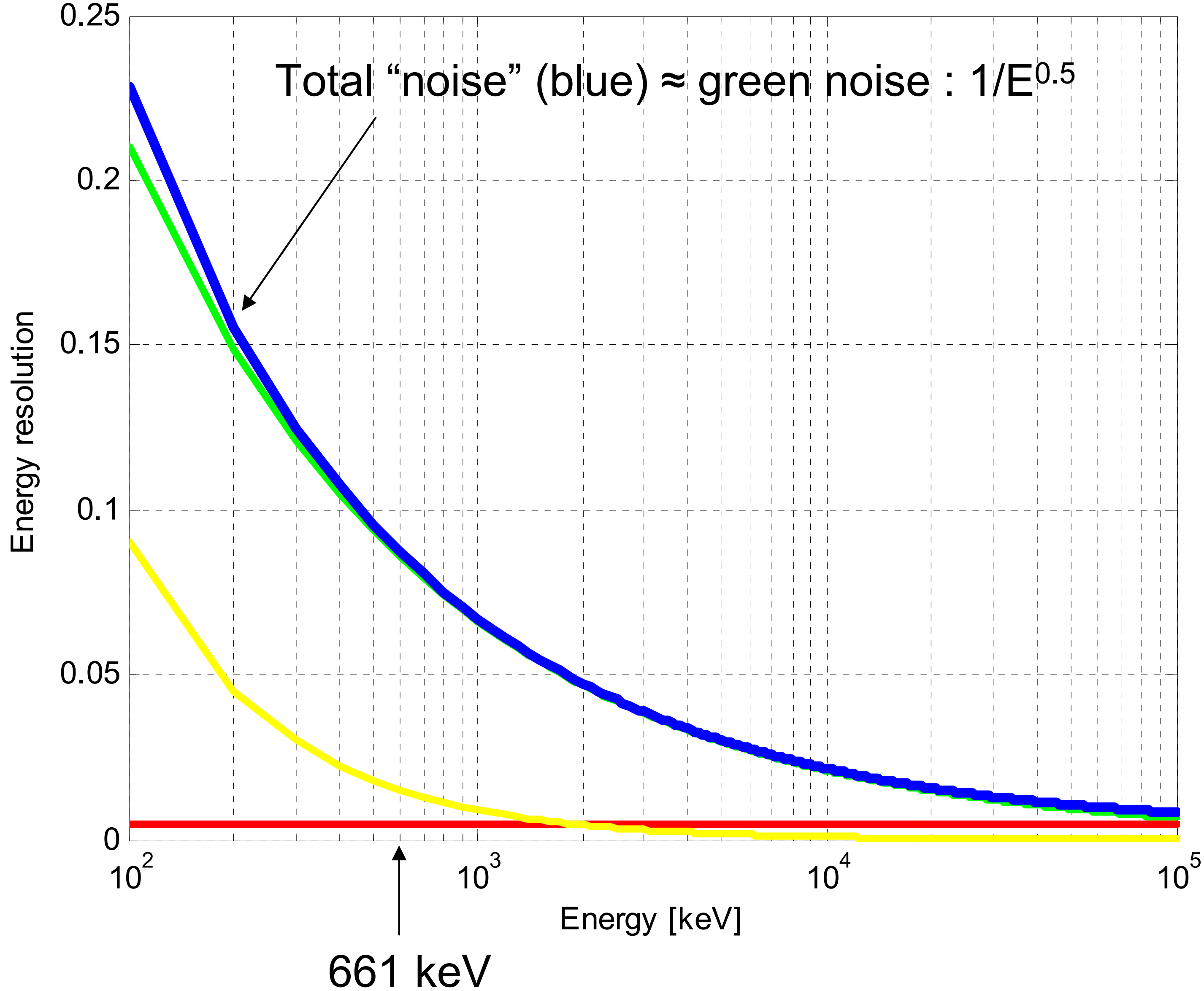
Important contribution
- at middle energy: A1

Important contribution
- at high energy: B1, B2, B3, B4

Classical noise sources

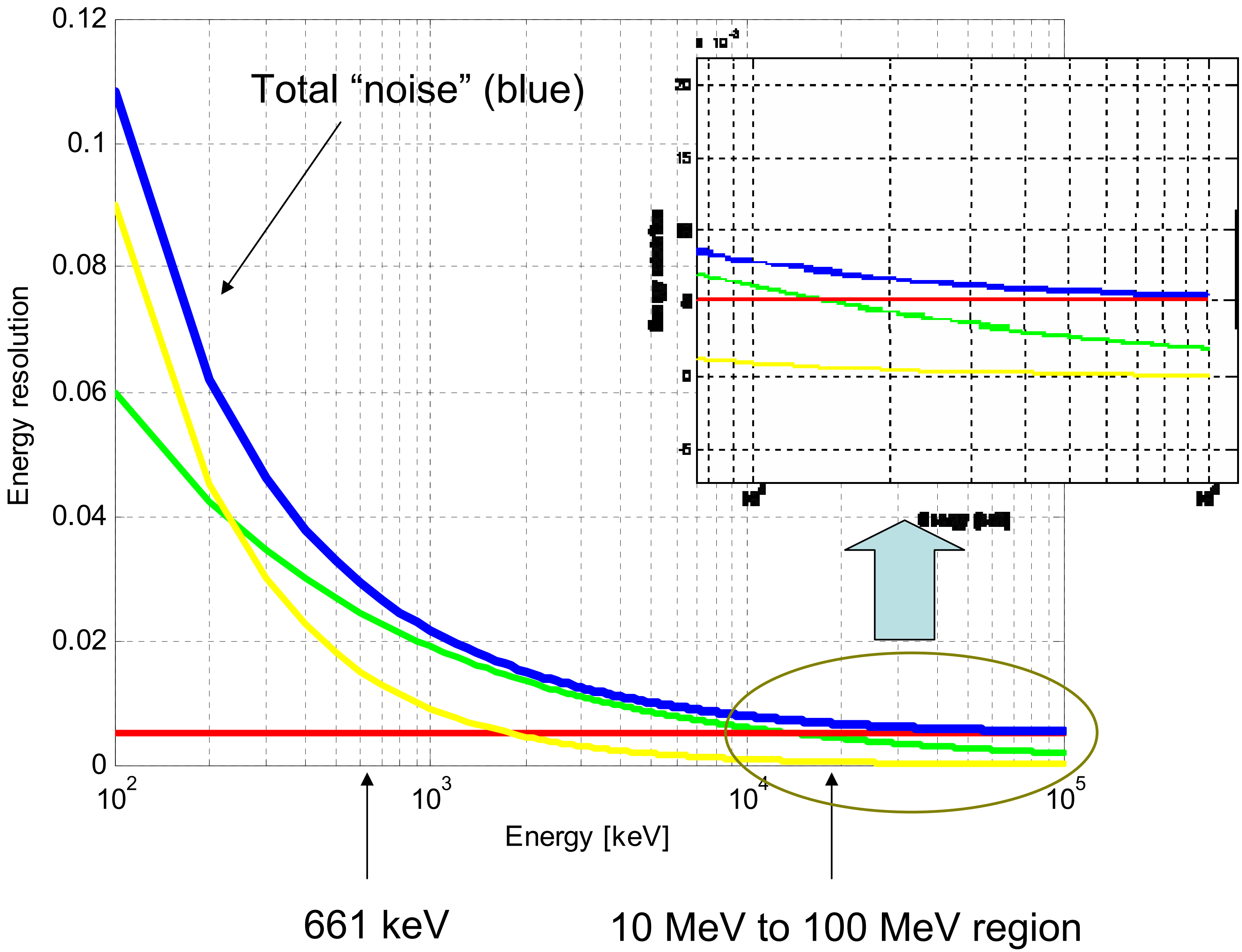
Deterministic and correctable effects

Example: BaF_2 scintillator

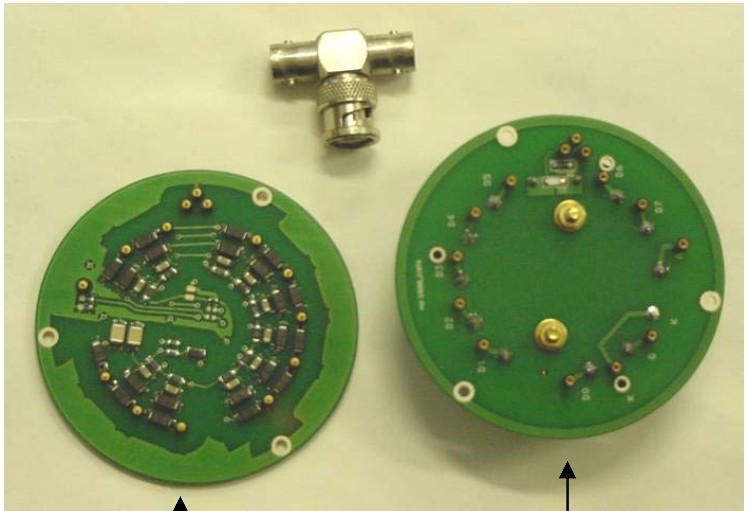


All contributions (A, B, C) are normalized to energy K

Example: $LaBr_3$:Ce scintillator

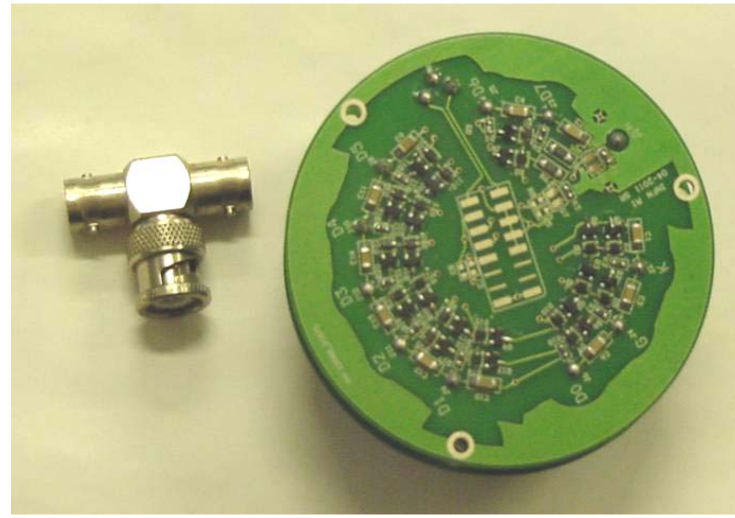


PMT front-end electronics



Adapter PCB
(to fit to different PMT sockets)

Active voltage divider PCB
(bottom side, showing protecting diodes)

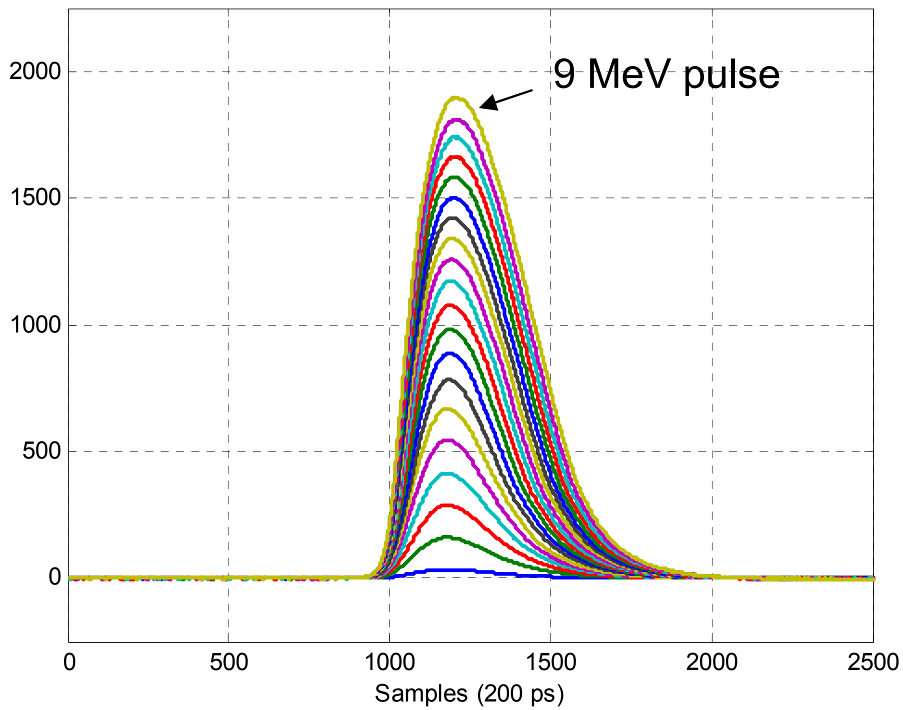


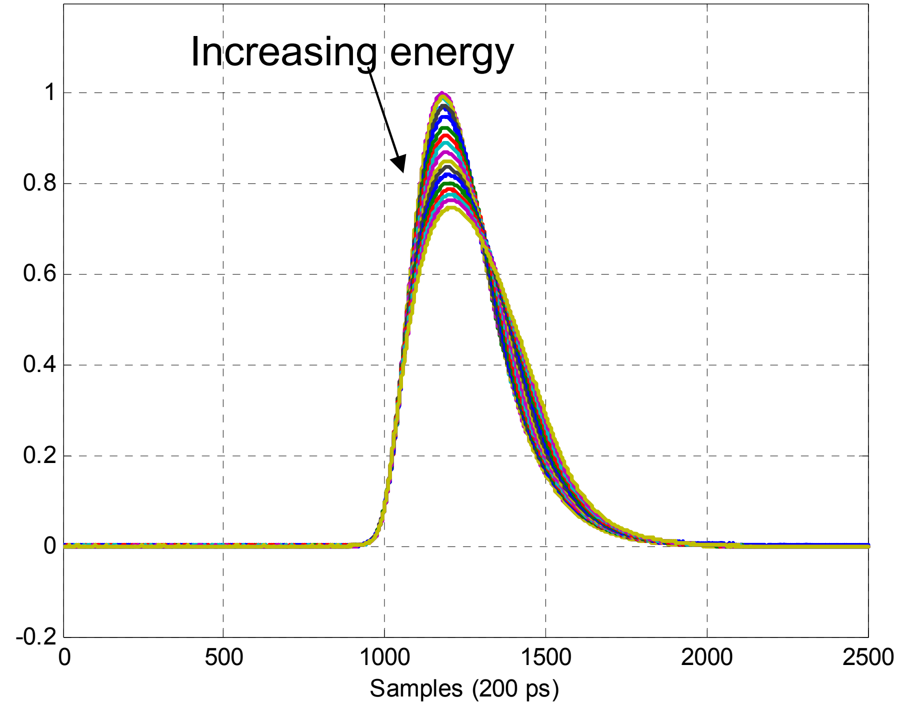
The two PCBs coupled together
(top side of VD, showing main electronics: BJTs, MOSFETs, etc.)

Third PCB (for readout and processing) in manufacturing phase

- Direct PMT output signal
- PMT amplified signal
- PMT signal integrated by CSP
- Temperature monitor
- High voltage monitor and stabilization (± 2%)
- Pulser for diagnostic and calibration
- Light emitting diode

PMT non linearity



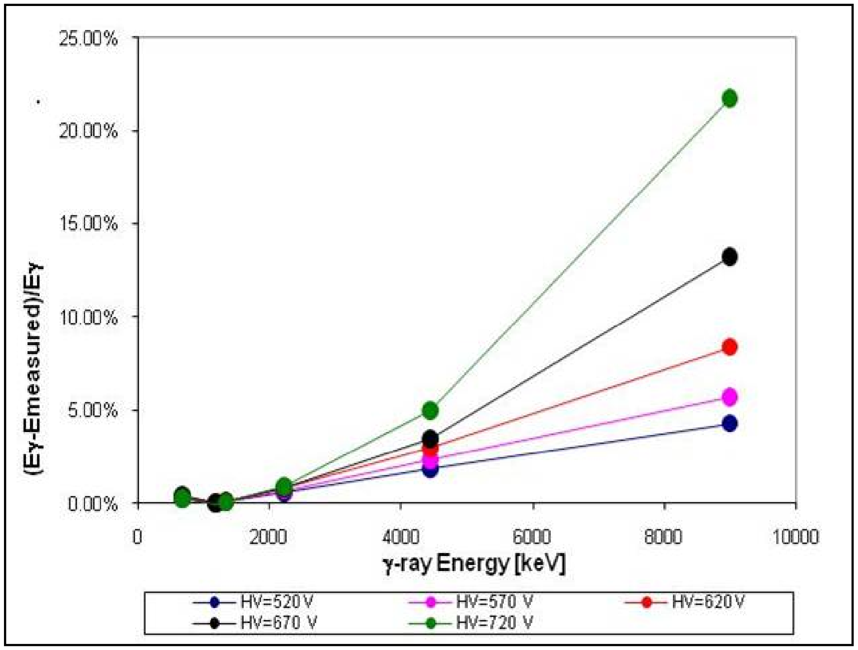


Experimental PMT output pulses (50 Ohm term.)

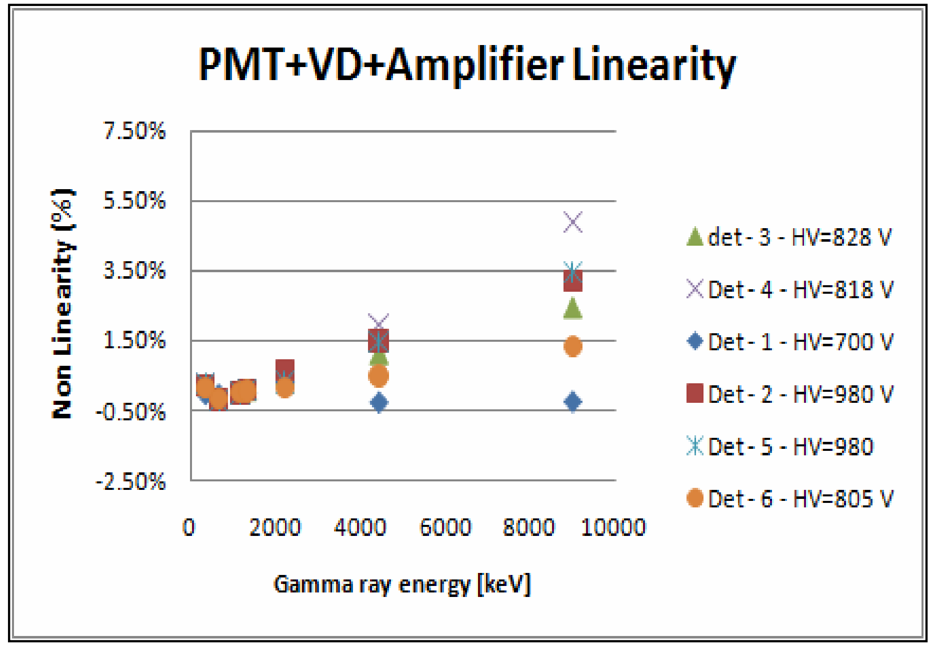
PMT pulses normalized to unitary area

As energy increases output pulse shape is more deformed, while the corresponding estimated energy gets lower and lower.

Non linearity estimation



Hamamatsu standard voltage divider

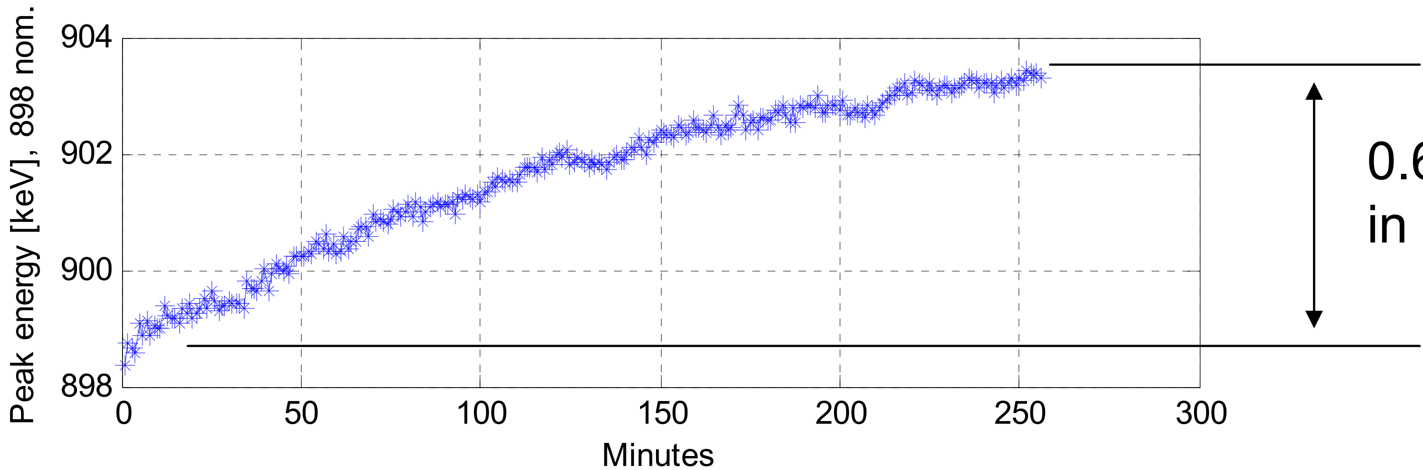


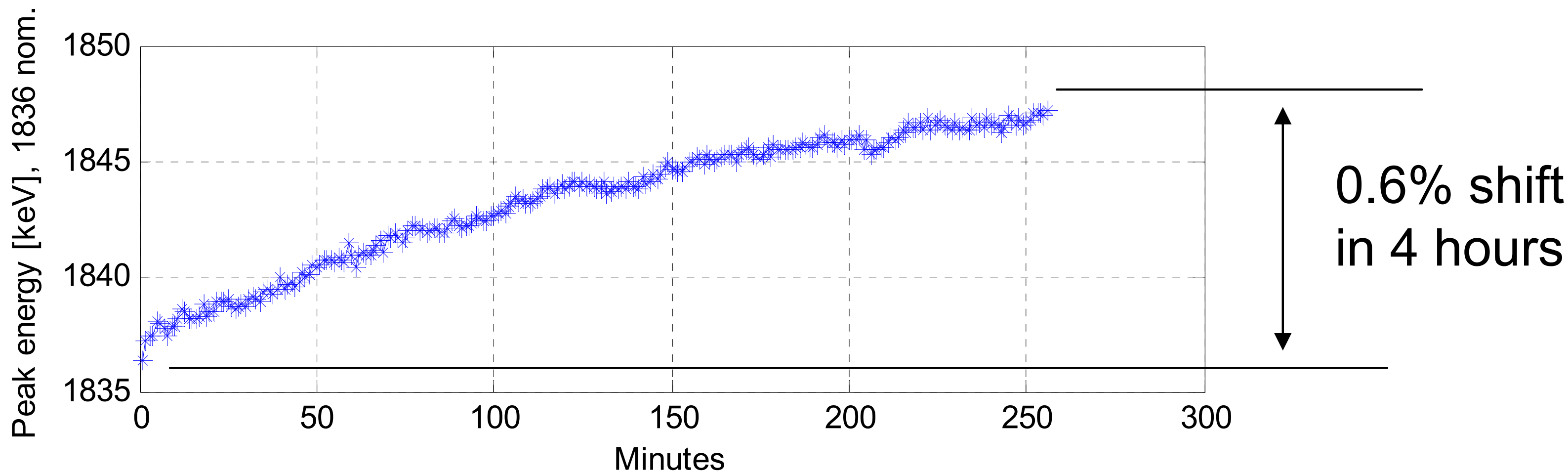
New active voltage divider

Subsequent measurements recently performed in Debrecen (Hungary) with det. #2 and det. #3 show as a preliminary result that:
det. #2 has non linearity error less than ± 1% up to 17 MeV
det. #3 has non linearity error less than - 3% up to 17 MeV

Peak fitting procedure is not trivial due to first escape peak and comton scattering
Additional analysis will be performed soon

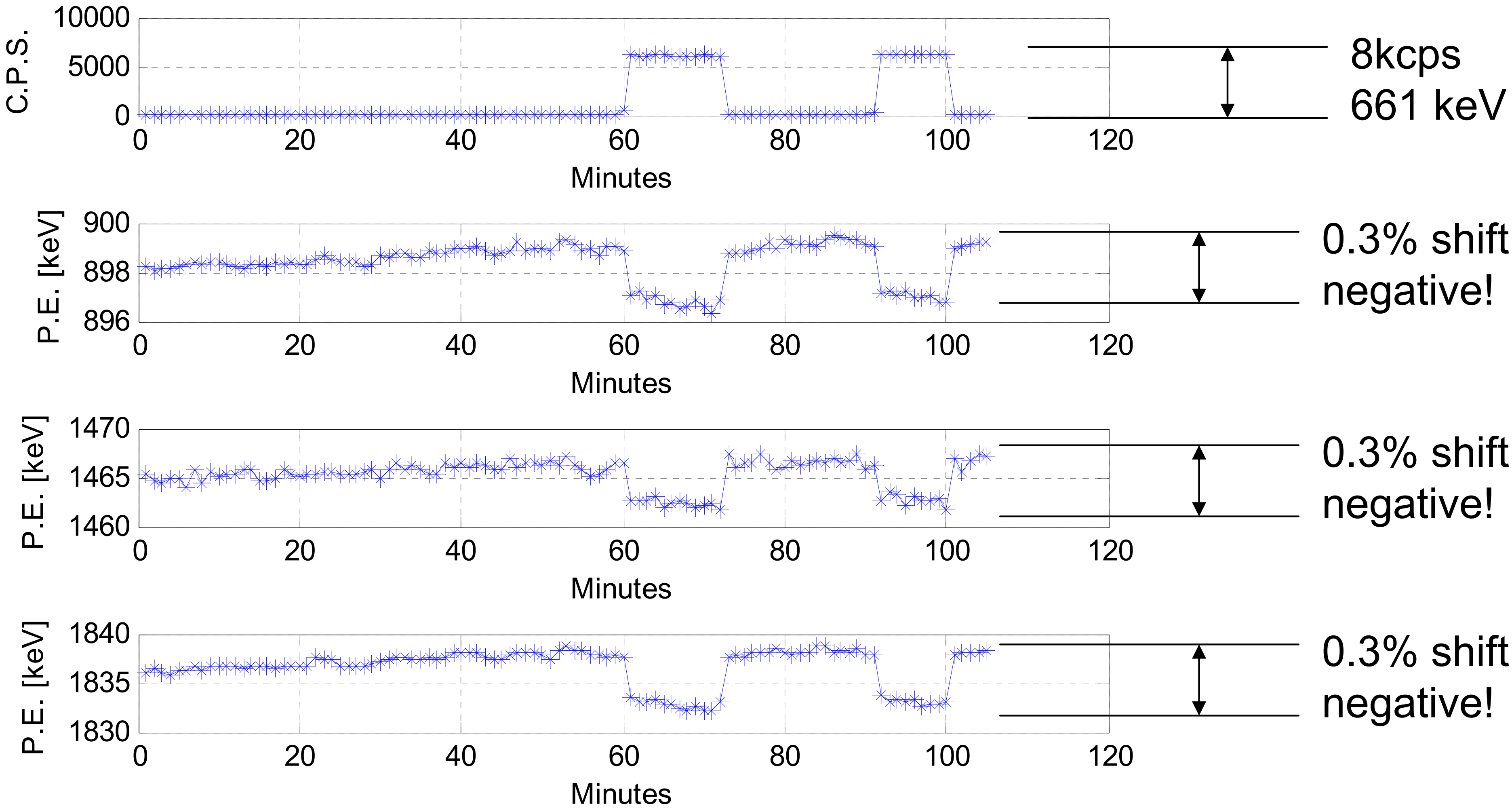
Temperature effect over time





- Acquisition performed after 24 hours of PMT warming up at constant HV
- Deterministic effect: can be corrected for, provided PMT temperature is known
- Need to be taken into account to get under 1% energy resolution

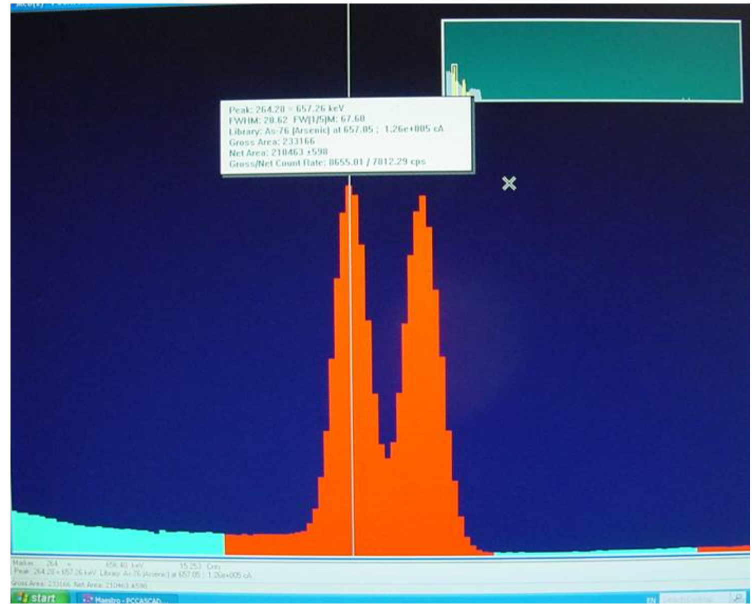
Counting rate effect



- No measurable peak shift effects was actually expected
- Standard voltage dividers always show shifts in the positive direction
- Analog electronics processing the PMT signal could be the cause
  (P/Z compensation, baseline restoration, etc.)
- Additional measurements with PMT digital sampled signal needed

Mu-metal shield for magnetic field

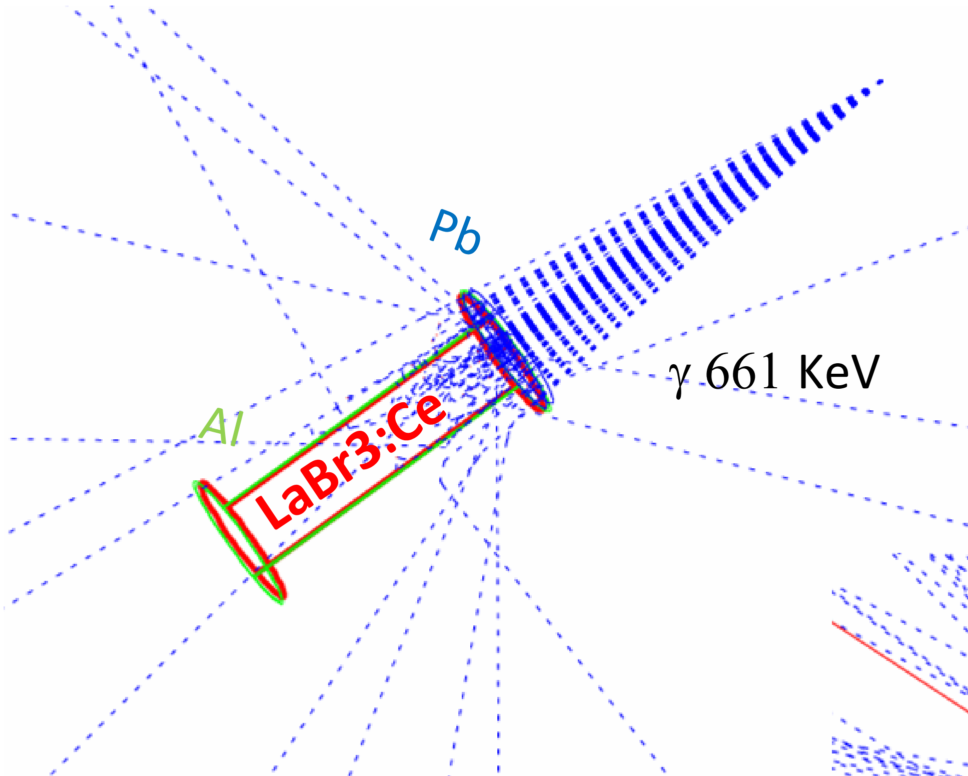
Re-cycled mu-metal shield
(for testing purpose only)



6% peak shift obtained by turning the detector by 30 degrees
(gamma source energy is 661 keV, peak resolution is 20.5 keV FWHM and absolute peak shift is 40 keV)

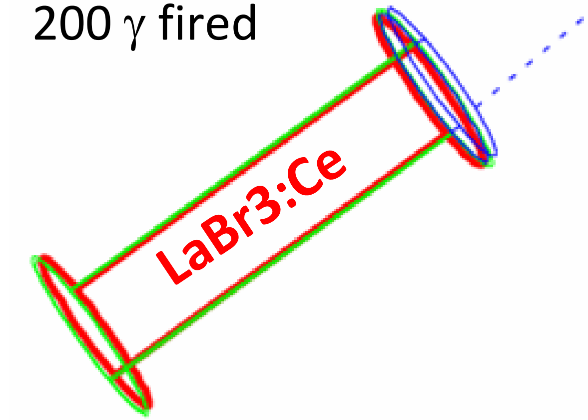
Dedicated mu-metal shields that fits the Aluminum enclosure from the inside are being manufactured by a private company and will be readily available
Mu-metal shields have already proved to be useful for experiments at GSI

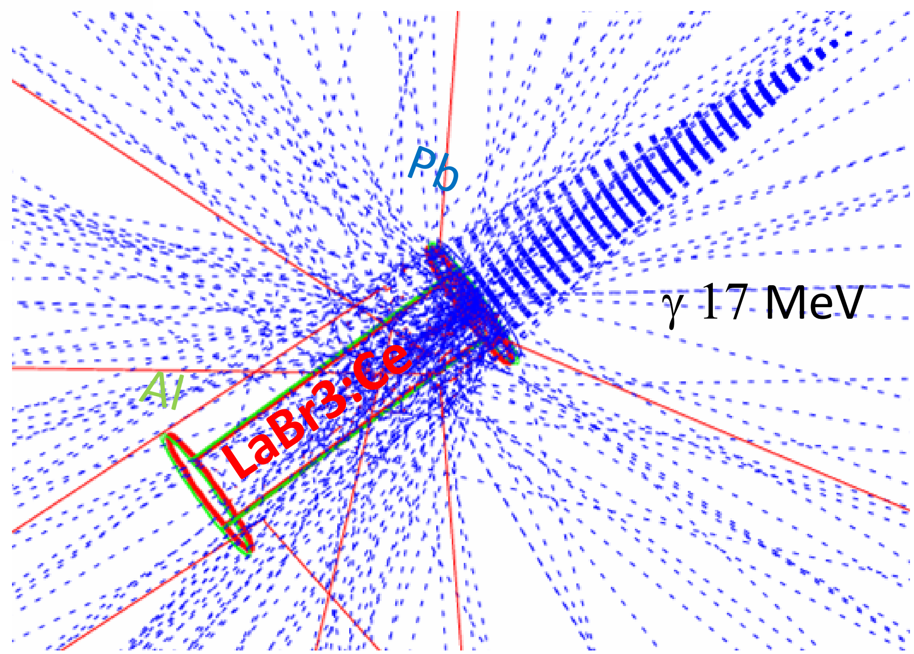
Interacting position of gamma rays



GEANT SIMULATION

200 γ fired



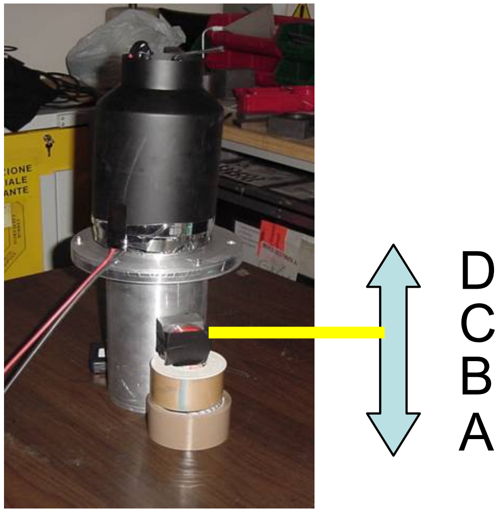


High energy gamma rays easily interact within the whole detector volume

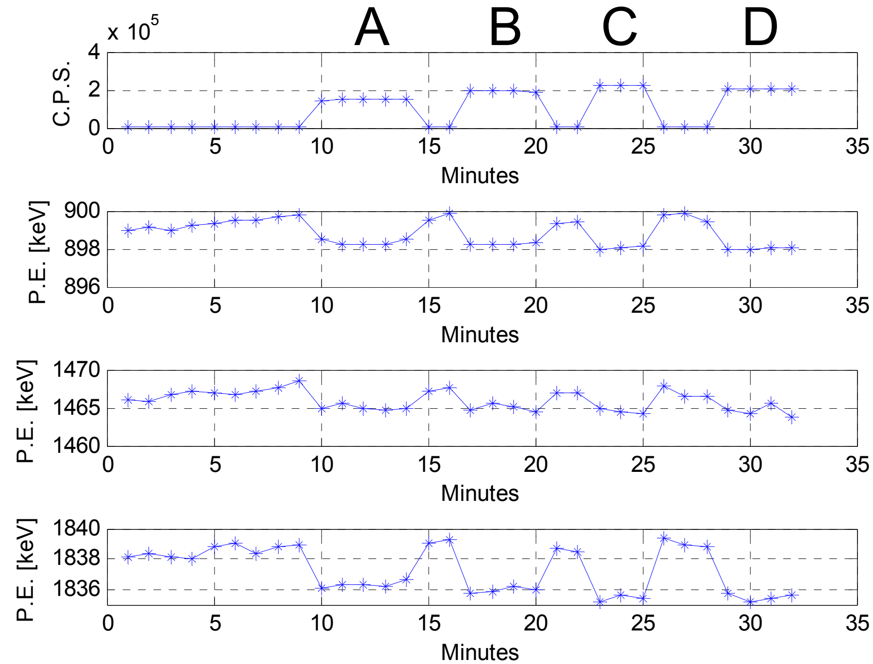
Non-homogeneities, i.e. in doping concentration may be another limiting factor (not easily correctable) for energy resolution

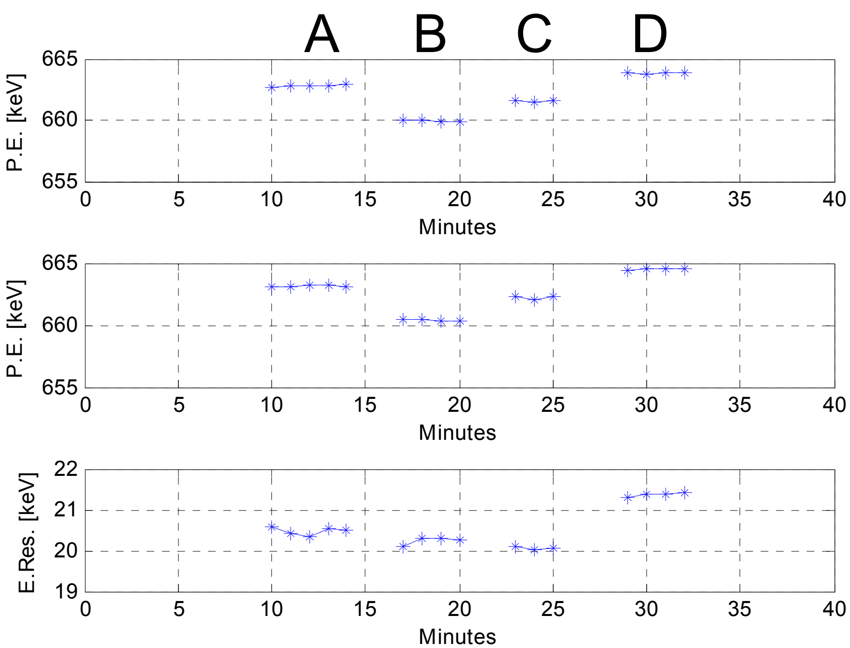
Simulations by O. Wieland

Non homogeneities within detectors



661 keV
"collimated"
gamma source





0.6% shift
in peak position

1.5 kev difference
in energy resolution

More investigation planned in the futurewith forthcoming mechanical set-up

Digital Algorithms for PSD

Digital signals of PMT pulses acquired by:

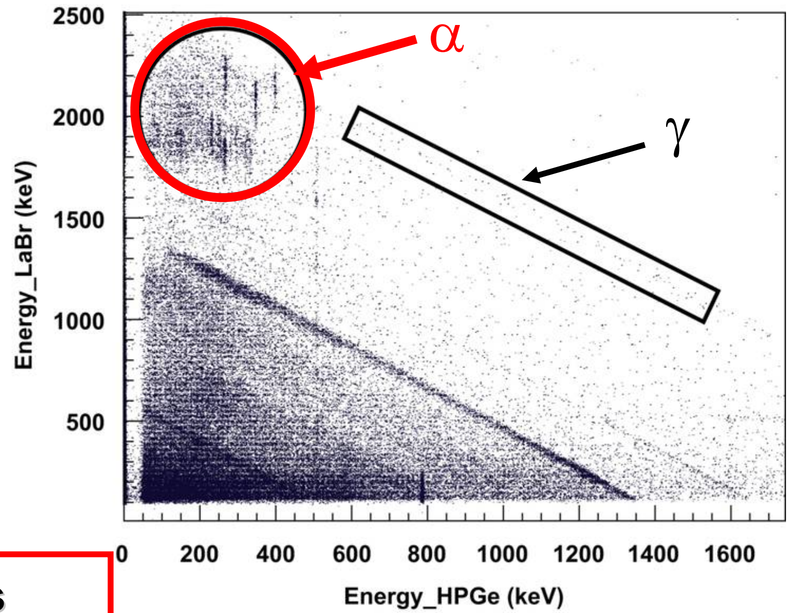
5 GHz, 8 bits Digital Oscilloscope

2 GHz, 12 bits ADC VME module

100 MHz, 14 bits ADC VME module

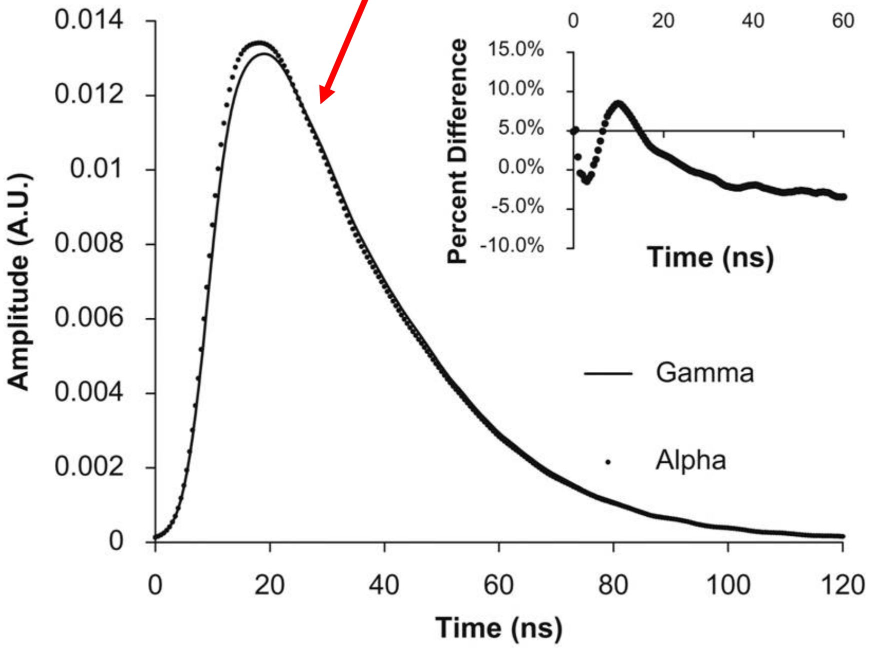
Processing algorithms are effective for a variety of sampling ADCs

PSD algorithm for $LaBr_3$, $LaCl_3$

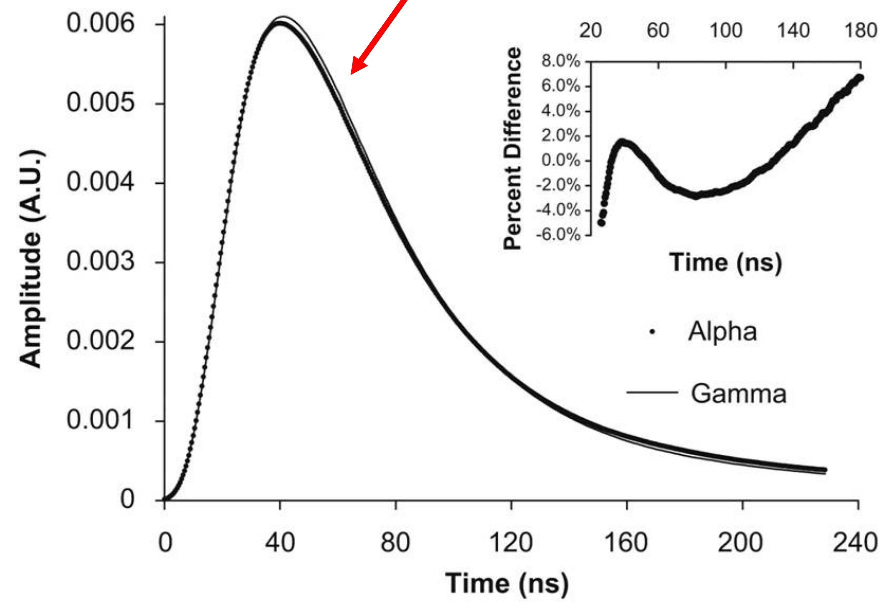


Matrix of coincidence events measured with LaBr3:Ce (*y*-axis) and HPGe (*x*-axis) detectors

Signal shapes of α-particles and γ-rays in LaBr3:Ce



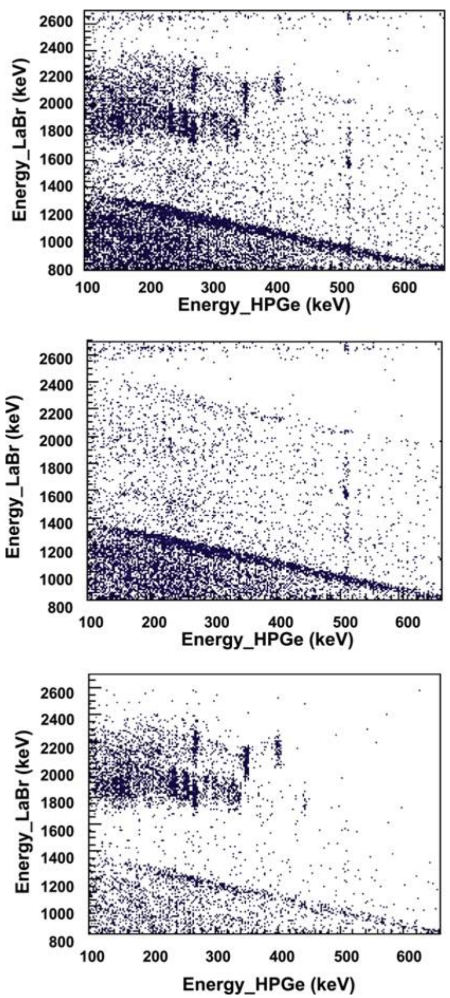
Signal shapes of α-particles and γ-rays in LaCl3:Ce



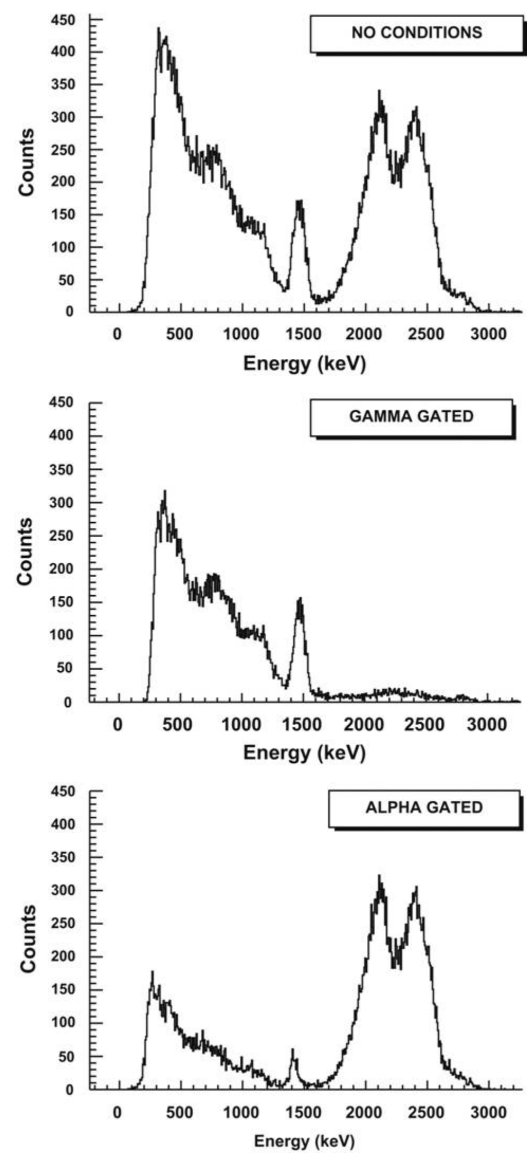
Application of the algorithm to internal radioactivity and natural background spectra

Selected region in the matrix of coincidence events (LaBr-HPGe) when:

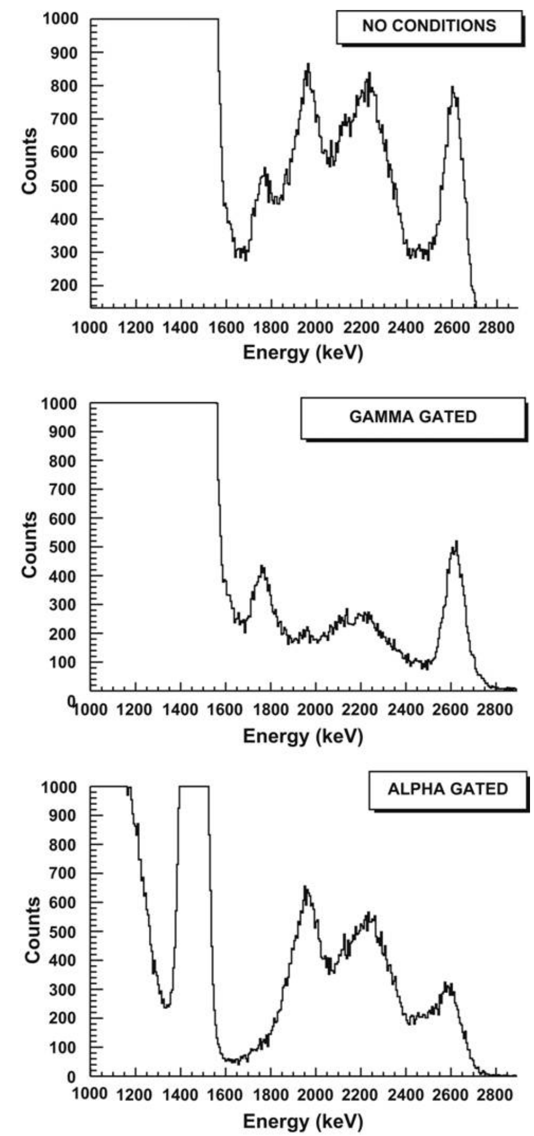
- no condition on I_0 is applied (top panel)
- selecting γ-rays, $I_0 < I_{thr}$ (central panel)
- selecting α-particles, $I_0 > I_{thr}$ (bottom panel).



$LaBr_3$:Ce



$LaCl_3$:Ce



New Mixed A/D Electronics for Scintillator Detectors

- Dedicated to $LaBr_3$, $LaCl_3$, BaF_2
- VME bus (modularity for multi-channels experiments)
- 8 Channels per board for PMT anode
- Modular design for channels
- Spartan6 FPGA + DSP on board
- Suitable for stand-alone operation
- Suitable for operation with AGATA system (via AGAVA)
- Low power consumption / low cost

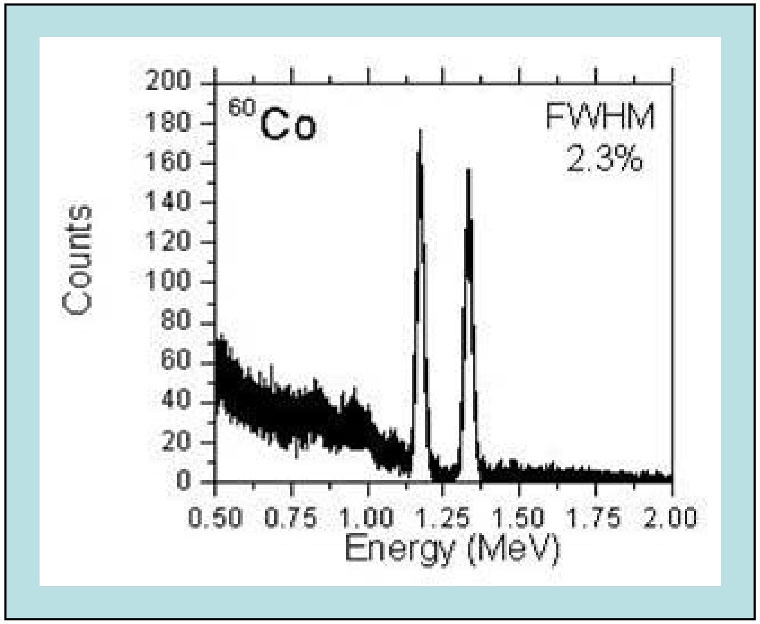
Thank you!

F. Camera, C. Boiano, N. Blasi, S. Brambilla, F. Crespi, A. Giaz,
B. Million, R. Nicolini, L. Pellegri, S. Riboldi, O. Wieland
and the whole Milano team

Mixed A/D Electronics for Scintillation Detectors

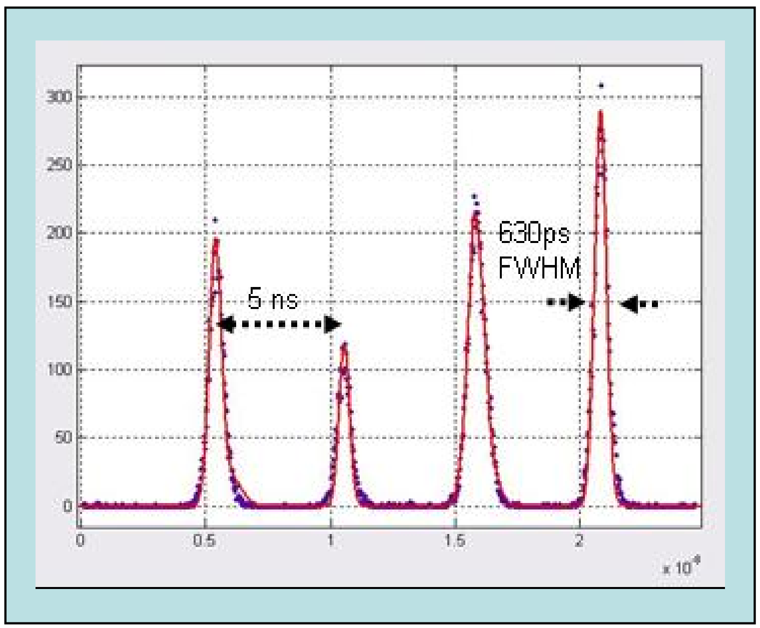
- Suitable for $LaBr_3$ and BaF_2
- 2-Channels Board (VME bus)
- Mother Board
  - DSP (TI TMS320C6203)
  - FPGA (XILINX XC4VSX35)
- Piggy-Back Boards (not shown)
  - A/D converter: 100 MHz, 14 bits
  - Shaping filter: 2 poles at 25 ns
  - Analog front-end (variable gain)
  - Discriminators

Experimental results with $LaBr_3$



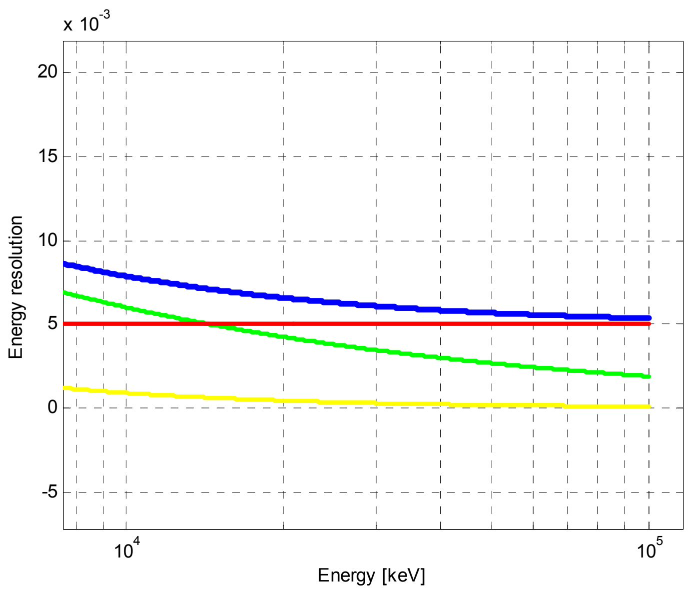
ENERGY MEASUREMENT

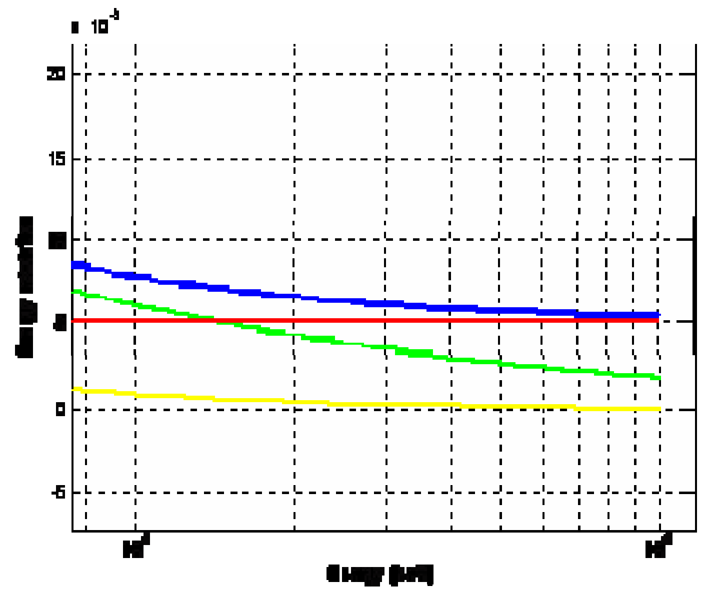
- Pulse signals integrated over time
- Energy resolution: 2.3% @ 1.33 Mev

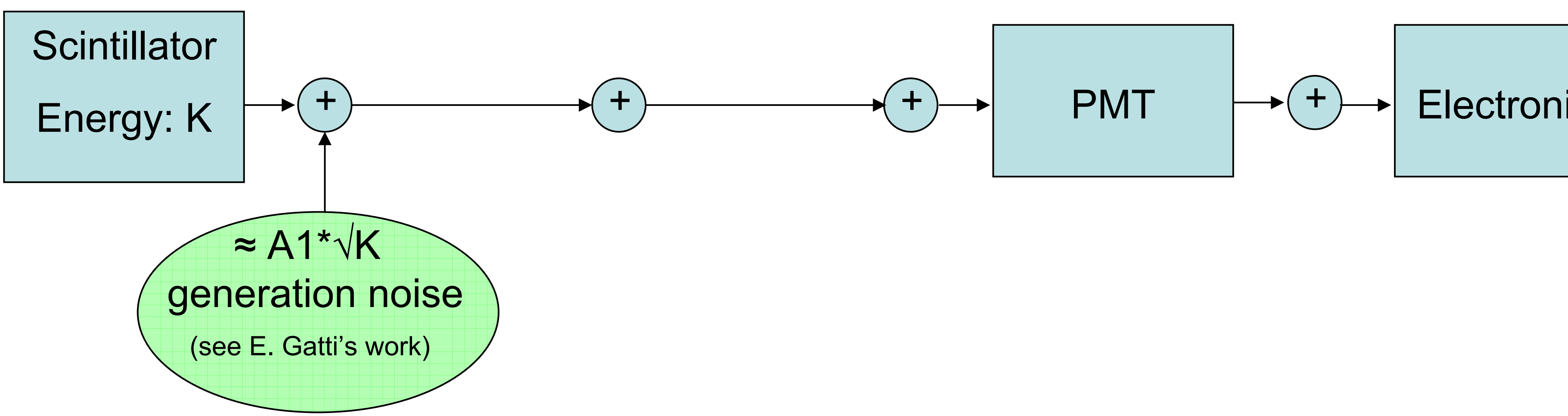


TIME MEASUREMENT

- 100 MHz free running ADC
- Digital signal processing of pulses
  - Optimum FIR Filter in DSP
- 630 ps FWHM (coincidence) time resolution @ 1.33Mev


x 10^-3
20
15
10
5
0
-5
Energy resolution
10^4
10^5
Energy [keV]


15
0
-5


Scintillator
Energy: K
+
+
+
PMT
+
Electroni
≈ A1*√K
generation noise
(see E. Gatti's work)