Planned upgrades of the DIAMANT light-charged-particle array

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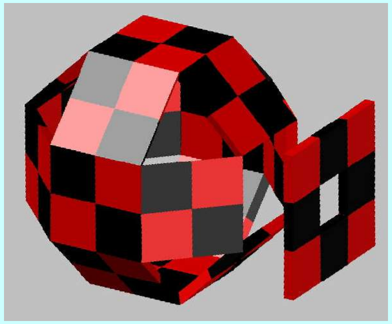
1. The DIAMANT history – Physics examples – Need for improvements
2. Mechanical upgrades of the DIAMANT
3. Detector developments
4. Software developments for digital electronics
5. In-beam tests of CsI+APD detector with analog & DSP electronics
6. Summary & Outlooks

1. The DIAMANT history:



DIAMANT is an ~ 4π, high-granularity light-charged-particle ancillary detector array for large γ-ray spectrometers (EB, EXOGAM, AGATA,...)

The collaboration:

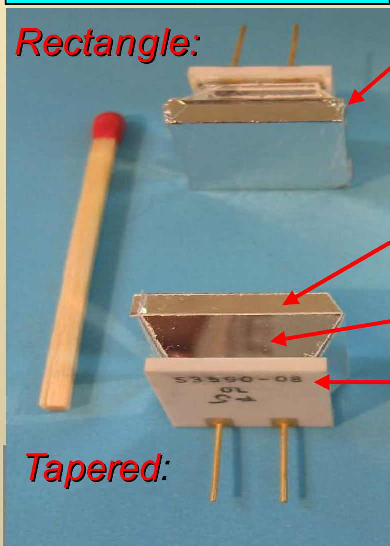
Past:	**CENBG** [J.N. Scheurer (retired '09) et al.]	
+		(original setup +)
Present:	**ATOMKI + Univ. of Debrecen** [B.M. Nyakó*) et al.]	
		(VXI, new setup, maintenance)
	Univ. of Napoli [G. La Rana et al.]	
+		(financial contribution +)
Future:	**IFIC** [A. Gadea et al.]; **GANIL** [G. de France et al.] (host/help)	

*) Contact person; nyako@atomki.hu

DIAMANT technicalities – the CsI(Tl) detectors:

CsI(Tl) scint. has an intrinsic Particle Discrimination capability ($\tau_\alpha \neq \tau_p \neq \tau_\gamma$)

The CsI detectors



d(CsI) = 3 mm:

$E_{proton} \leq$ 25 MeV

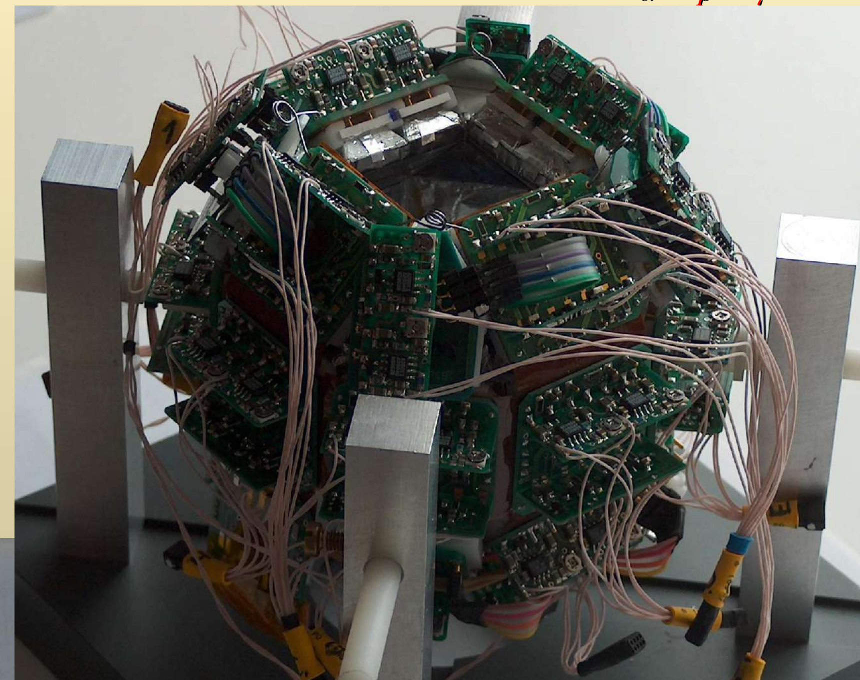
$E_{alpha} \leq$ 100 MeV

CsI, in special wrapping:

> 80% light coll. effic.

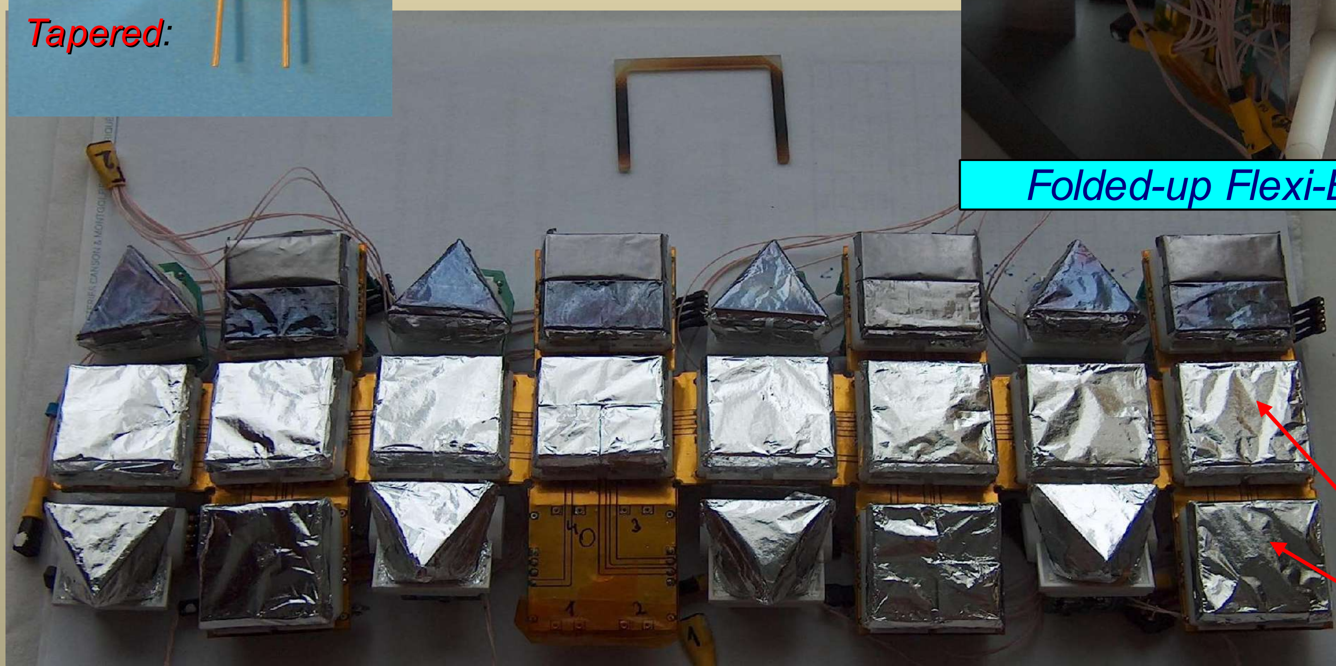
Plexi-glass lightguide

PIN-photodiode



Folded-up Flexi-Board on service stand

Efficiency:	[% of 4π]
geometrical:	≈ 90
det. protons:	≈ 70
det. alphas:	≈ 50



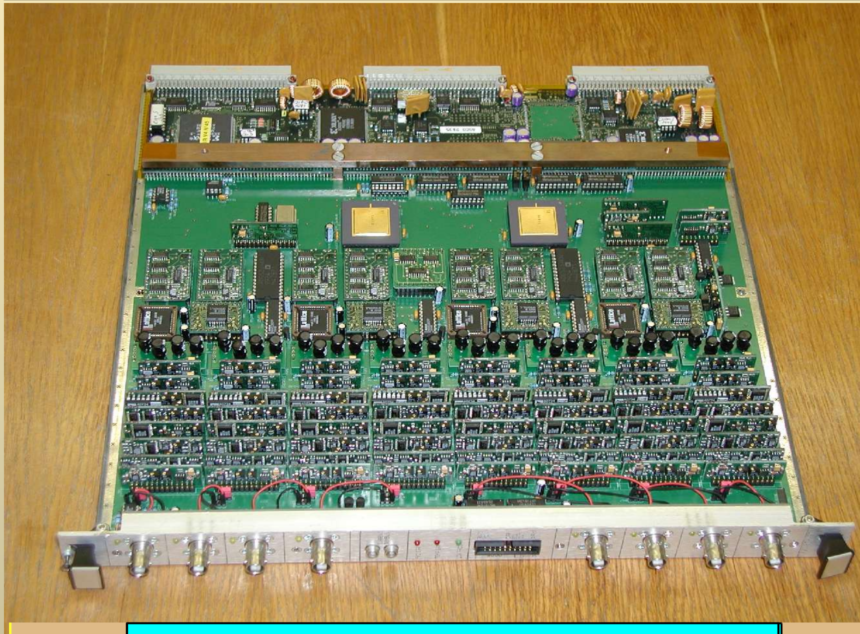
Quad CsI-s

Tapered CsI detectors assembled on the Flexi-Board (EXOGAM)

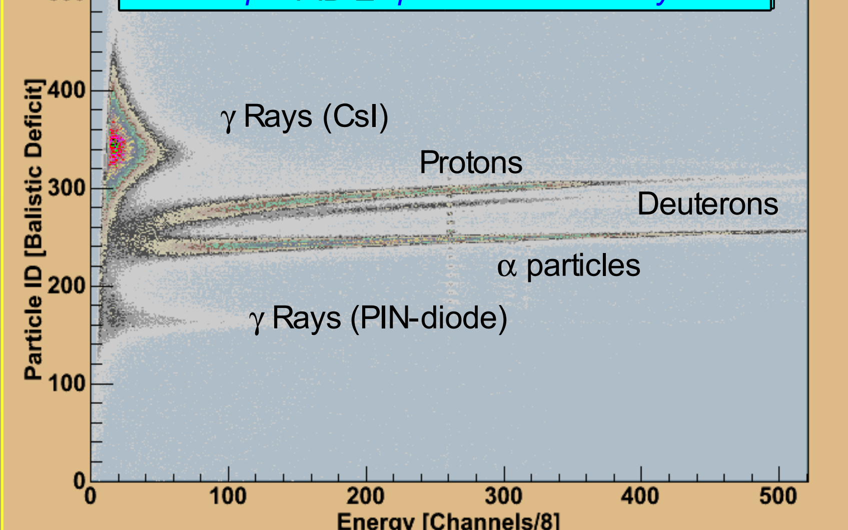
DIAMANT technicalities – the VXI electronics:

Particle Discrimination is based on Ballistic Deficit method; Outputs: Energy, PID, Time

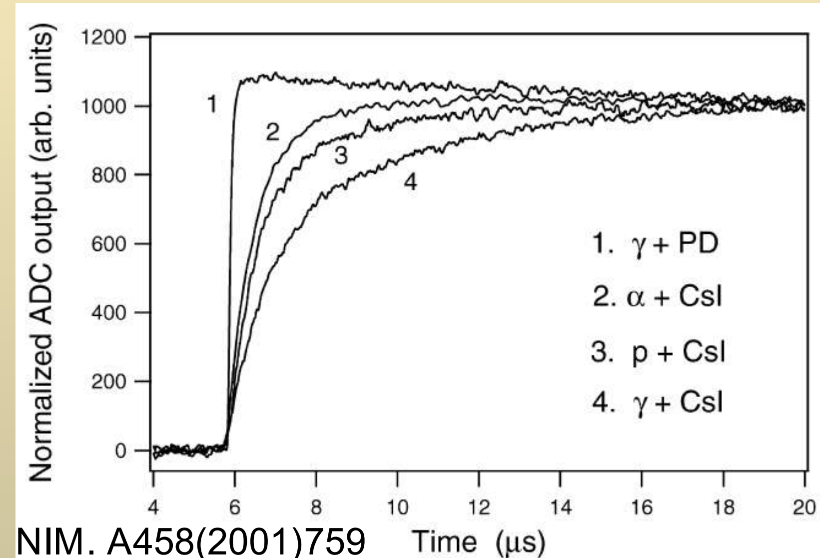
The Octal Part. Discr. Card in VXI standard



Example PID-E spectrum of a CsI crystal



The Ballistic Deficit method :



NIM. A458(2001)759

Degradation of pulse height: risetime and shaping-time dependent!

Gating on charged particle spectra in

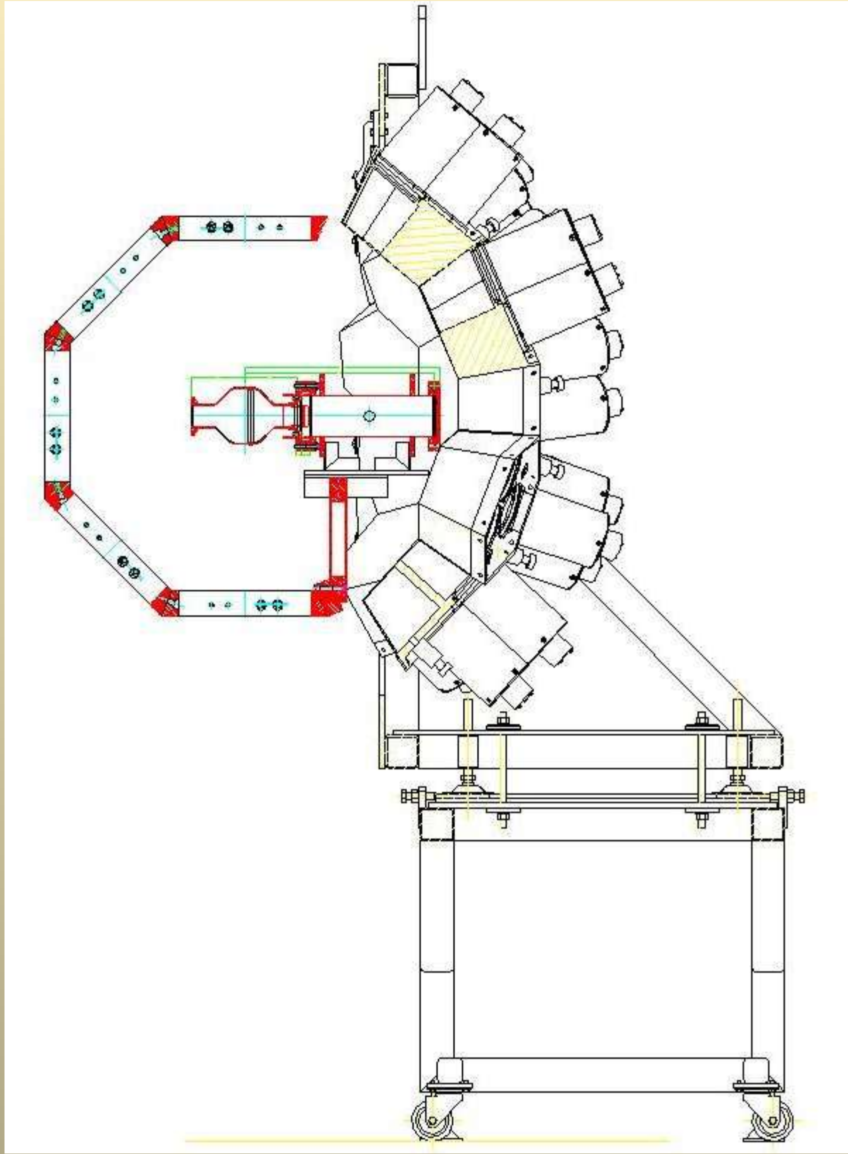
1D (Time, PID) or

2D (PID–E, PID–Time, Time–E)

enables:

- *selection/rejection of reaction channels*
- *rejection of random events*
- *enhancement of gammas with special conditions*

DIAMANT has been used in many EB, EXOGAM + N-Wall, AFRODITE experiments



DIAMANT wrt. EXOGAM + N-Wall

Hyperdeformation: (EB) selector + rejector

Chiral-search: (EB) selector;
(AFRODITE) rejector

N=Z: (EXOGAM): rejector

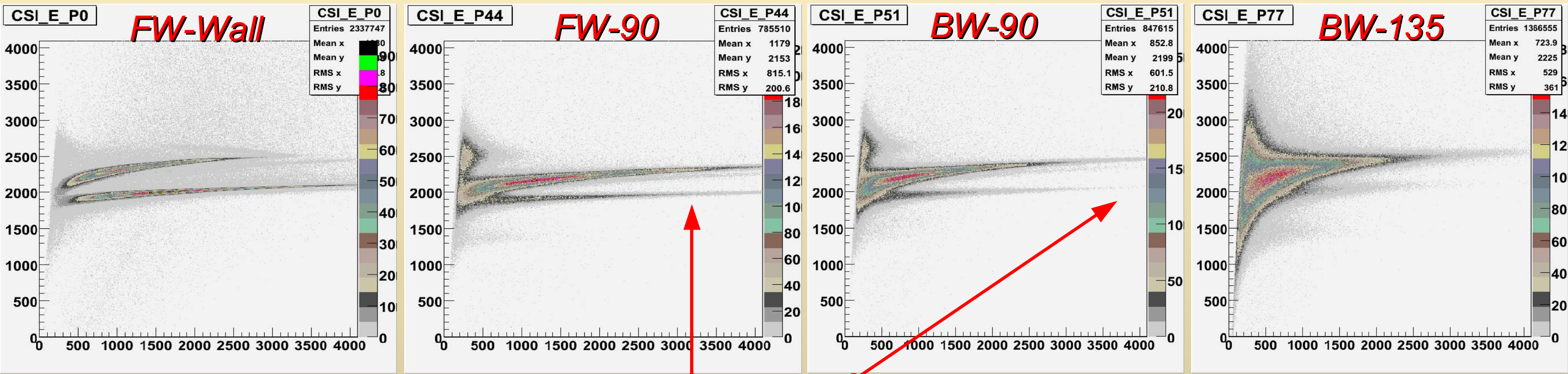
Successful use of exp. setup including DIAMANT as veto-detector:

Results from exp. E451a: Search for T=0 pairing and a new coupling scheme in ^{92}Pd and ^{88}Ru by Bo Cederwall et al.,

has been published in Nature (2010)

B. Cederwall et al., New spin-aligned pairing phase in atomic nuclei inferred from the structure of 92/46Pd46

Example spectra for the performance of DIAMANT: (Thick enough Ta absorbers)



Effect of (self)absorption on alpha-energy is obvious

Can be all OK for rejecting all charged part. channels, but if part discr. needed backward (BW) detectors are less or not at all performing!

Particular interest may be Doppler correction of gamma-energies for "alpha-push" of recoils.

Need for an upgrade of the detectors, as well as the electronics to improve the overall performance of DIAMANT: low-energy limit of particle discrimination , eliminate noise, improve signal to noise ratio,...

Plans have been made to upgrade DIAMANT detectors and replace VXI electronics with digital signal processing.

Plans For Further Improvements (PF2I)

To match the performance of DIAMANT with that of furture gamma-detector arrays EXOGAM-2 & AGATA, intended for nuclear structure studies with high intensity stable and radioactive beams, further improvement is a must!

Known Problems:

a. Troublesome installation of DIAMANT in the target chamber

b. CsI calibration, Target loading vs. efficiency, Vacuum feed-through

*c. Limitations due to γ-absorption for E_γ < 200 keV: **CsI(Tl)**, PAs, cables*

d. Problematic maintenance of the DIAMANT VXI cards: obsolate parts,

Planned Improvements:

e. Mechanical upgrades of the DIAMANT chamber

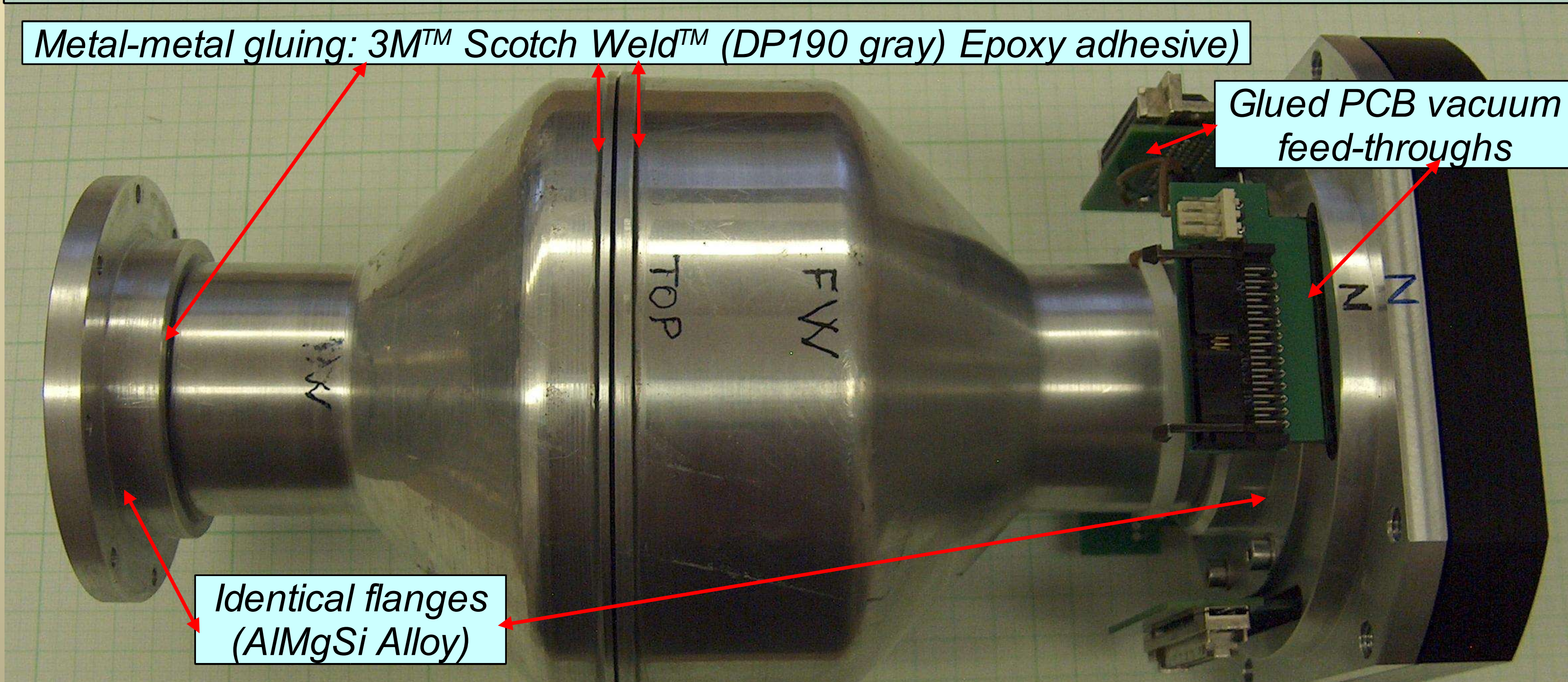
f. Use of high efficiency light detectors: test the applicability of Avalanche PhotoDiodes (APD) for CsI-s in DIAMANT

g. Use Digital Signal Processing: make the CsI electronics compatible with next-generation DAQ systems

2. Mechanical upgrades of DIAMANT: (ad. PF2I. a-c & e)

2a) Re-design of the mechanics for the DIAMANT chamber (Aluminum, where possible)
Shape is kept, flanges are standardized, glued --> grounding OK!

The NEW chamber of DIAMANT (used in the '09 EXG experiments)



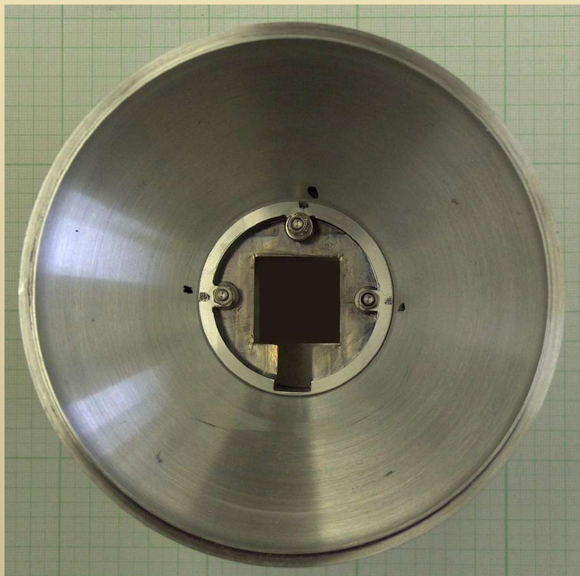
2b) Glued PCB feed-throughs: solution adapted from DIAMANT @ AFRODITE (TLABS, SA)

2c) T&B high-density connectors replaced by SCSI-2 connectors (Chamber, 2nd-stage PreAmps)
To ensure better shielding/grounding of ribbon (output) signal cables

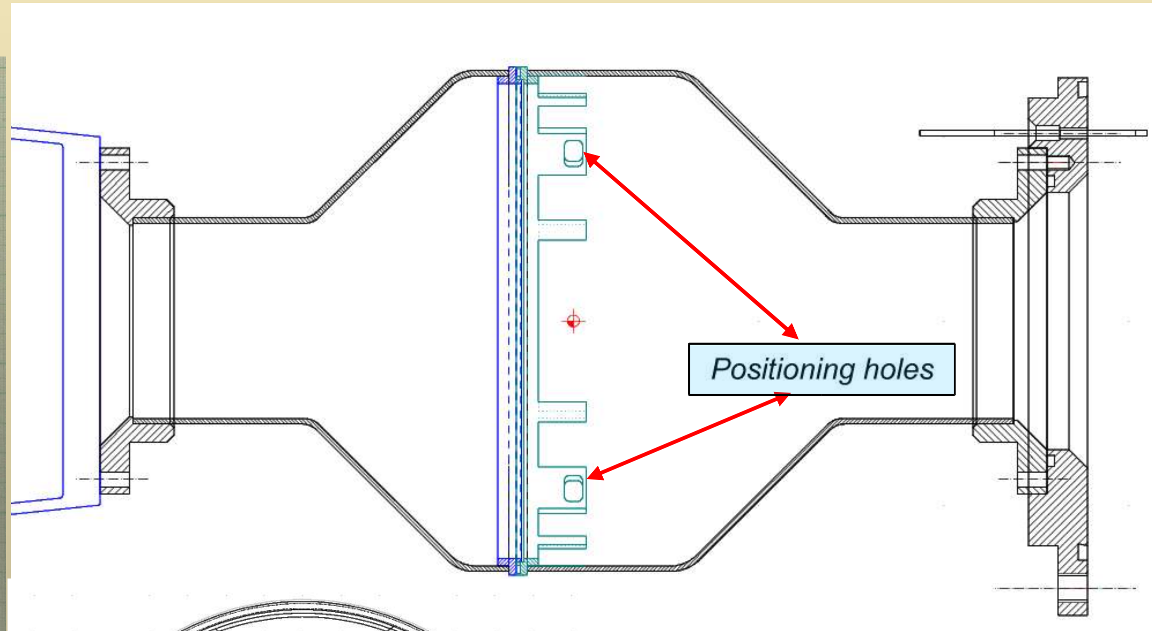
Excellent overall vacuum perfomance: $p_{He\text{-}4} < 10^{-9}$ bar; (Tested at ATOMKI)

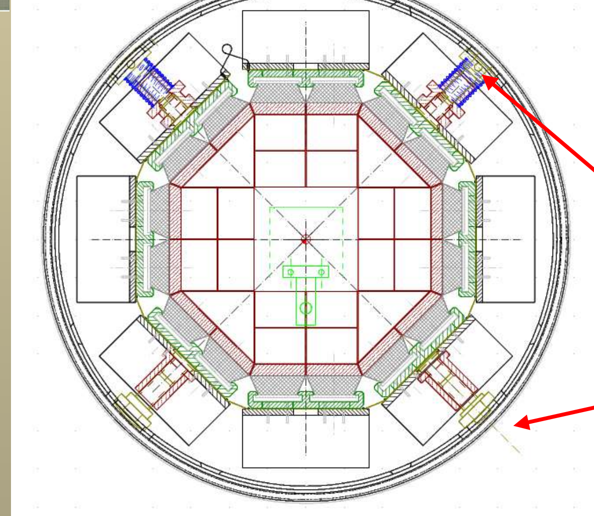
2d) Improved reproducible/stable installation of the FlexiBoard using positioning holes

Use of new beam collimation prevents the FlexiBoard etc. being hit by the beam to avoid dirt inside (Important for new setup with APD-s)



Upstream view of the collimator





Downstream view of the FlexiBoard X-section with positioning/adjusting legs

3. Detector developments: *(ad. PF2I a & f)*

Motivation: *Improve the performance of DIAMANT as for particle discrimination w. r. to low-energy separation limit;*
Lower the gamma-ray absorption (reduce material)

Solution: *Use of high-gain Avalanche-PhotoDiodes instead of pin-PDs*

Status: *Feasibility studies of using APD-s instead of pin-PDs started within the EXOGAM-2 section of the SPIRAL2-PP FP7 project*

Task 7 of the FP7 project: SPIRAL2-PP *(task responsible: ATOMKI)*

Implementing the pulse shaping algorithm into an FPGA for charged particle discrimination with CsI detectors.

An FPGA-based new instrumentation with four digitizing channels has been designed, which has to be interfaced to an improved version of DIAMANT-style CsI(Tl) detectors. The pulse shaping algorithm is based on the existing analogue solutions.

Deliverables:

- *Test of the improved version CsI detector.*
- *Pulse shaping algorithm running on FPGA.*

Feasibility studies of using Avalanche PD-s with DIAMANT CsI detectors

a) *Basic measurements with APD-s*

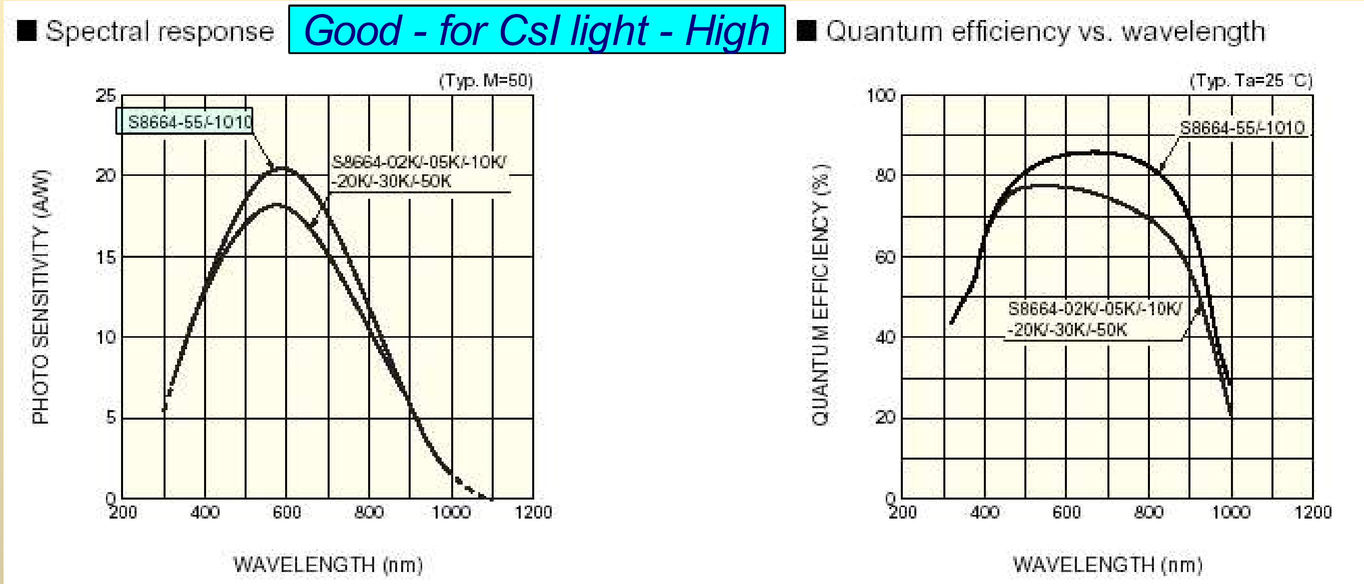
b) *Designing low-power consumption PA for APD-s*

c) *Noise & Ballistic Deficit measurements for DIAMANT CsI detectors*

d) *PID-vs-Energy spectra for CsI detectors using PIN-photodiode and APD readout with DIAMANT Part. Discr. electronics*

Properties of short wavelength type APD-s:

Advantages:



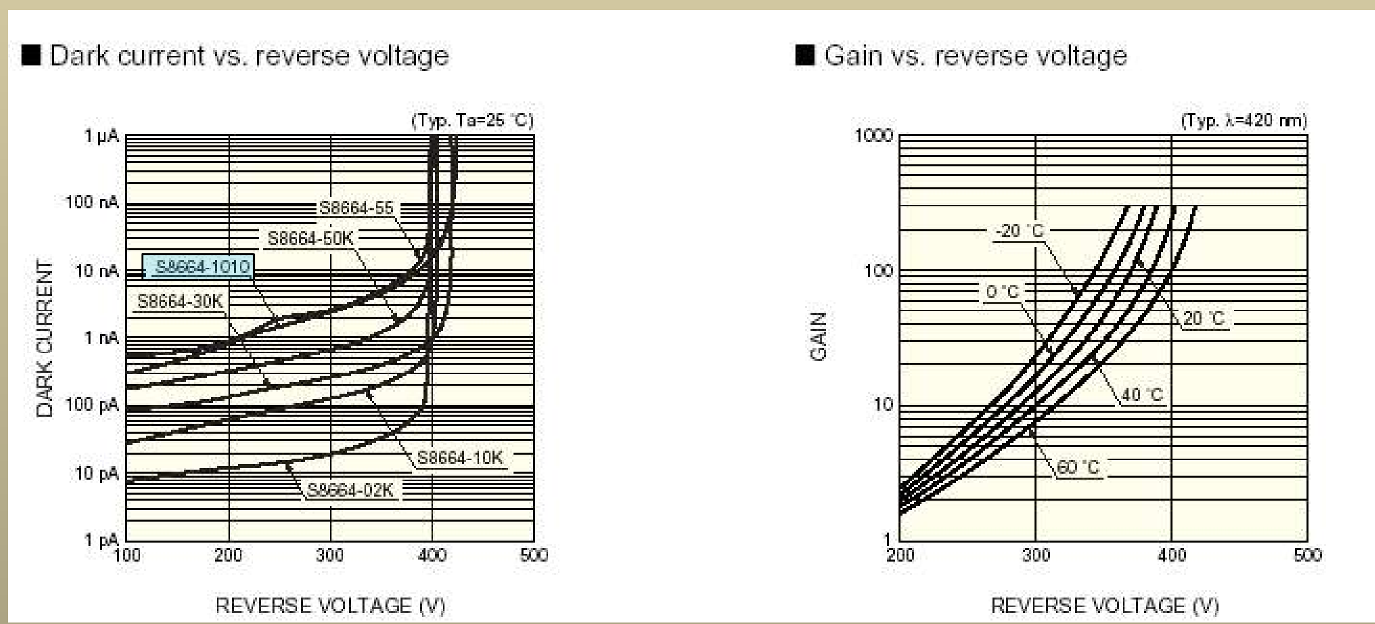
low dark current at V_{bd}

(V_{opt}~ 350V)

gain ~ 50 (T=20 C)

From: Hamamatsu Data Sheet

Disadvantages:



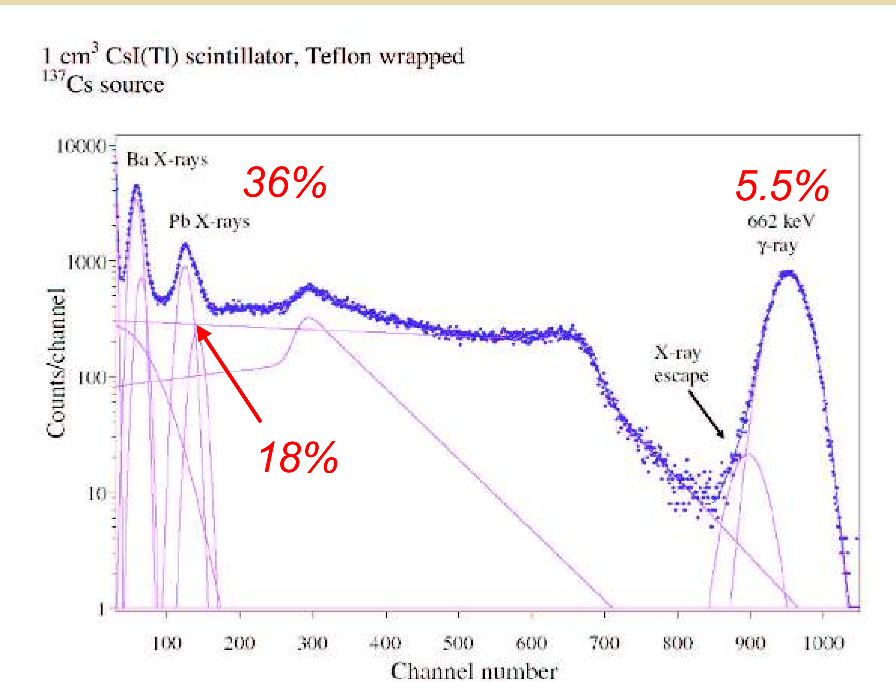
Needs high Voltage PS
(opt. ~350-400 V)
--> precautions

Temperature dependent
gain --> stabilisation

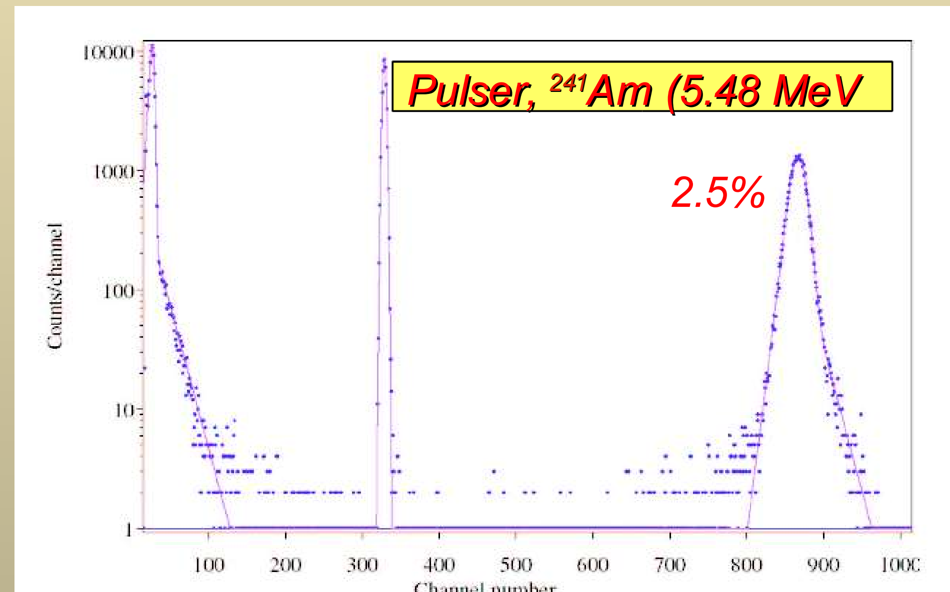
3a) Basic measurements with APD-s

Performance Test of CsI(Tl) + APD with gamma and alpha sources

^{137}Cs gamma-ray source



DIAMANT-CsI + APD, ^{241}Am source

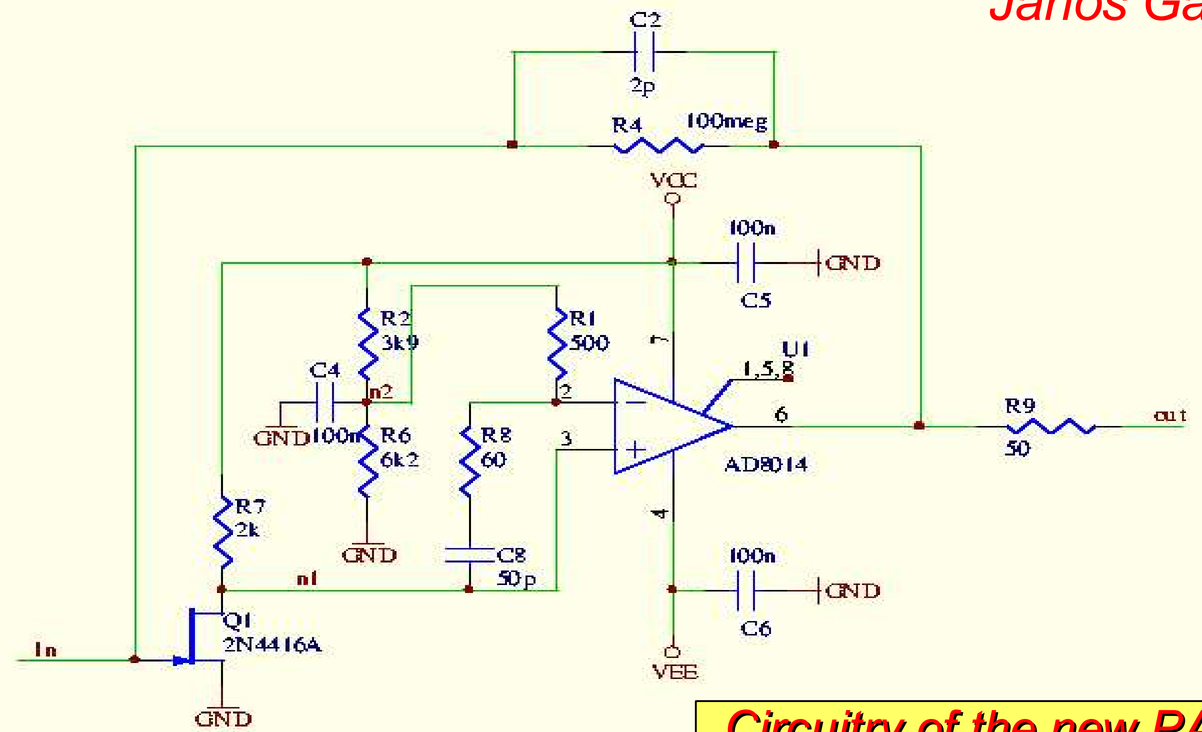


Conclusions: CsI(Tl) + APD can be used for low-energy γ-spectroscopy as well as for charged-particle spectroscopy and discrimination (see later!)

3b) Designing a low-consumption PreAmplifier for APD-equipped CsI-s

Aim: Design a low power consumption small size (in-vacuum) PA for APD-s, make prototype, determine optimal parameters, test performance

János Gál

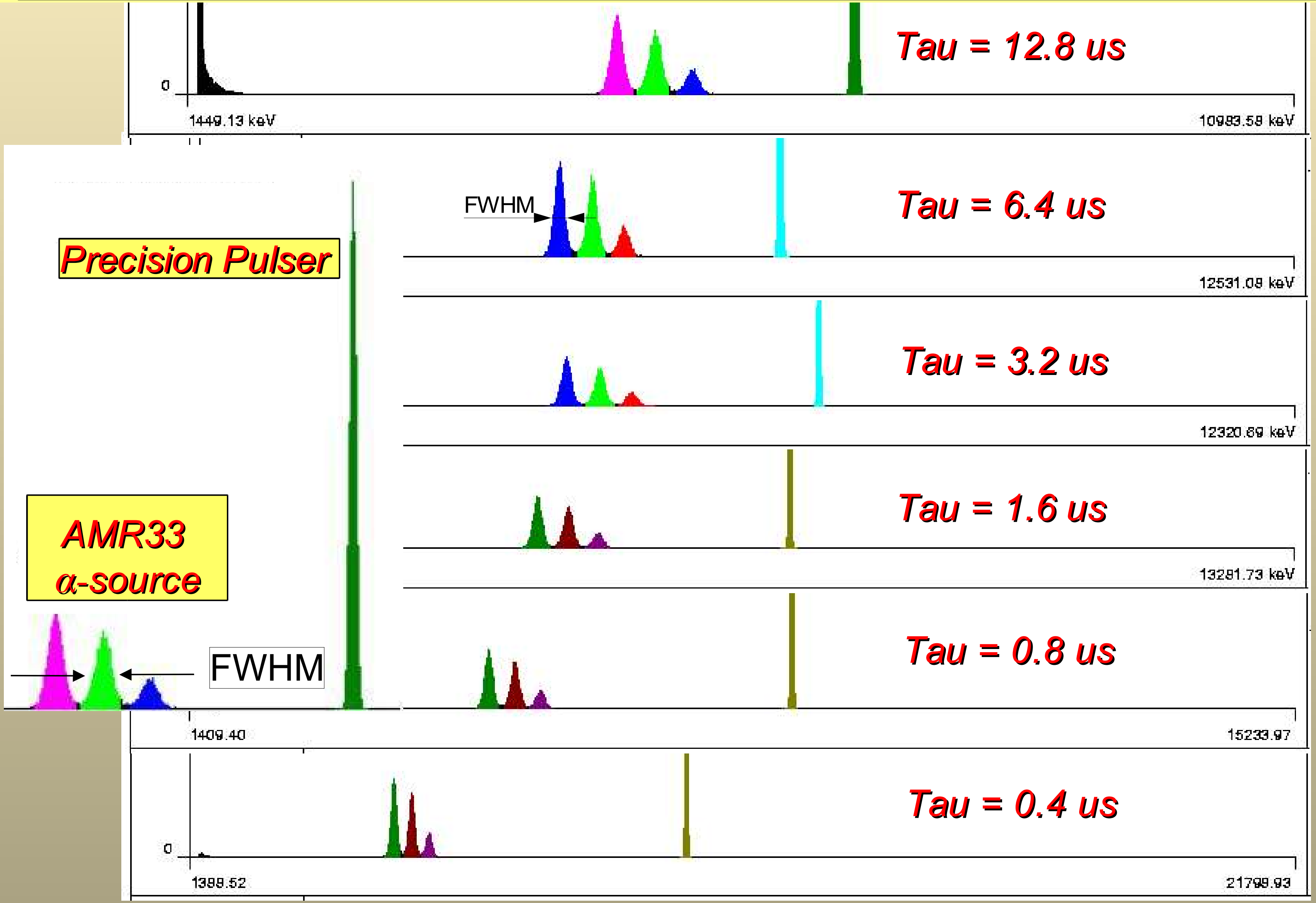


Circuitry of the new PA

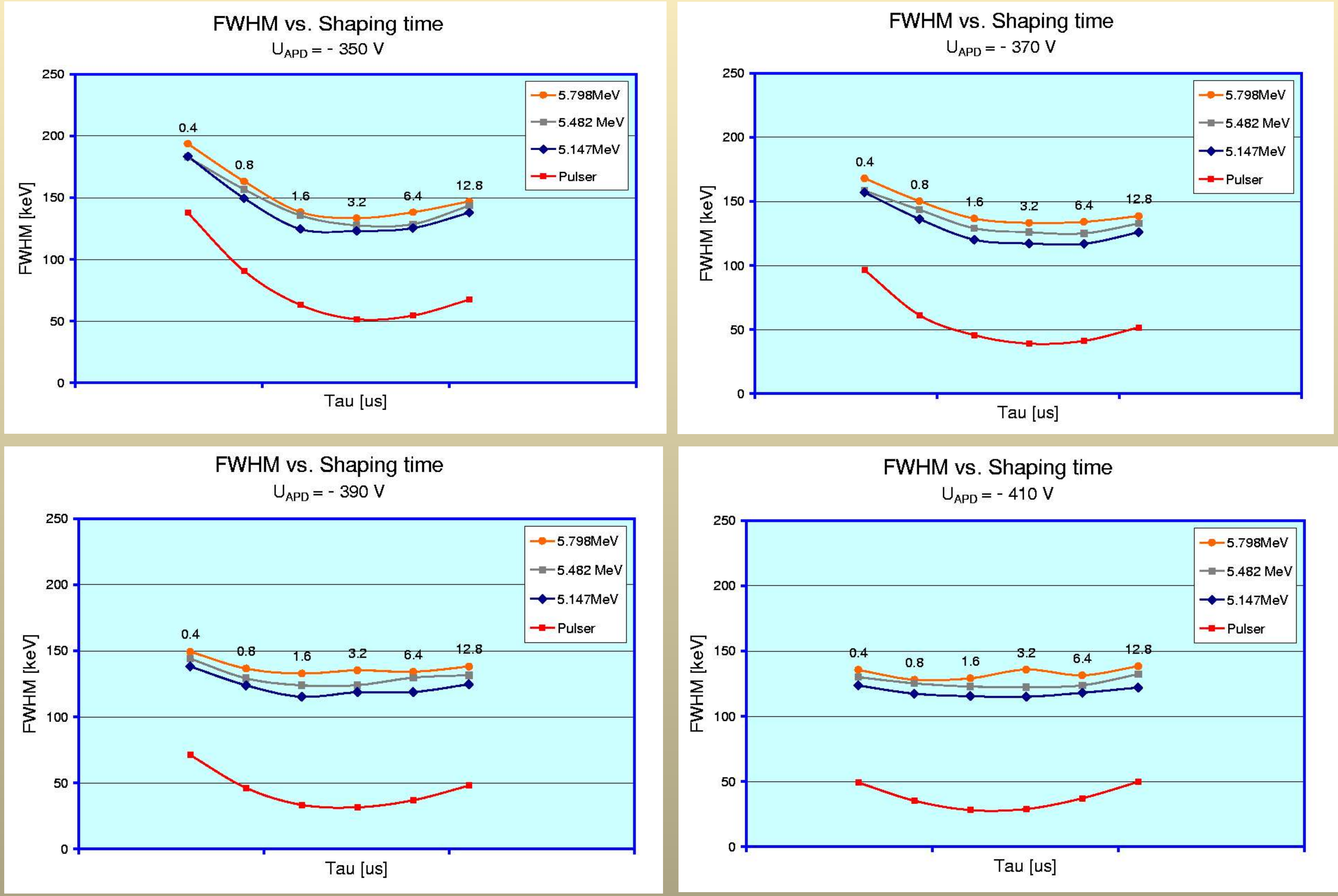
Results: Prototype made, tested/used with APD-s & PIN-PD-s;
Used for determining optimal parameters for FPGA programs to be applied for particle discrimination with DSP

3c) Noise & Ballistic Deficit measurements for DIAMANT CsI detectors

Method: *Measure the FWHM & Ballistic deficit for alpha source lines for different shaping times and U_{APD}-s, using a Precision Pulser and precise calibration*

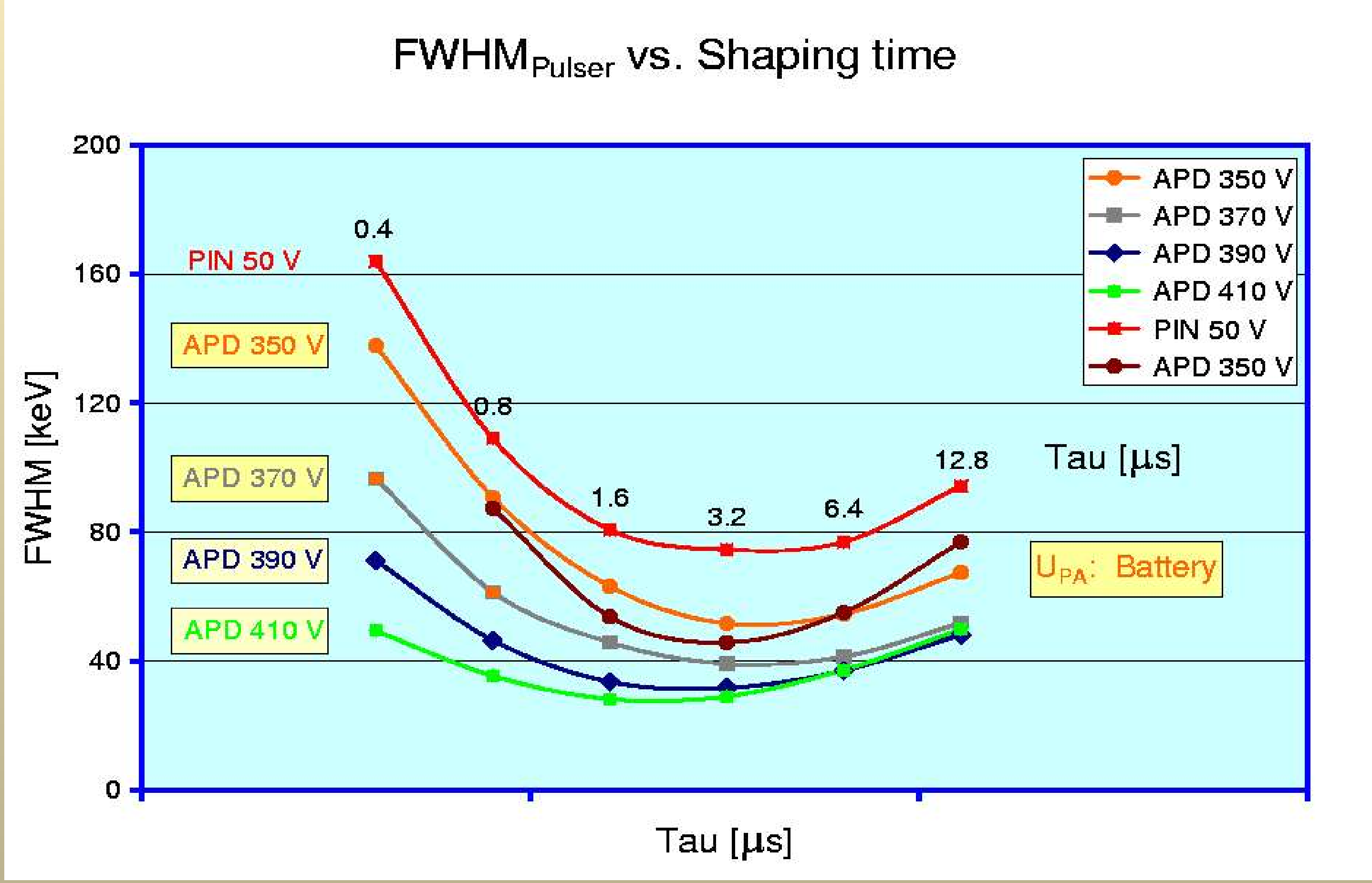


Noise & Ballistic Deficit measurements – the results:



Noise & Ballistic Deficit measurements – the noise:

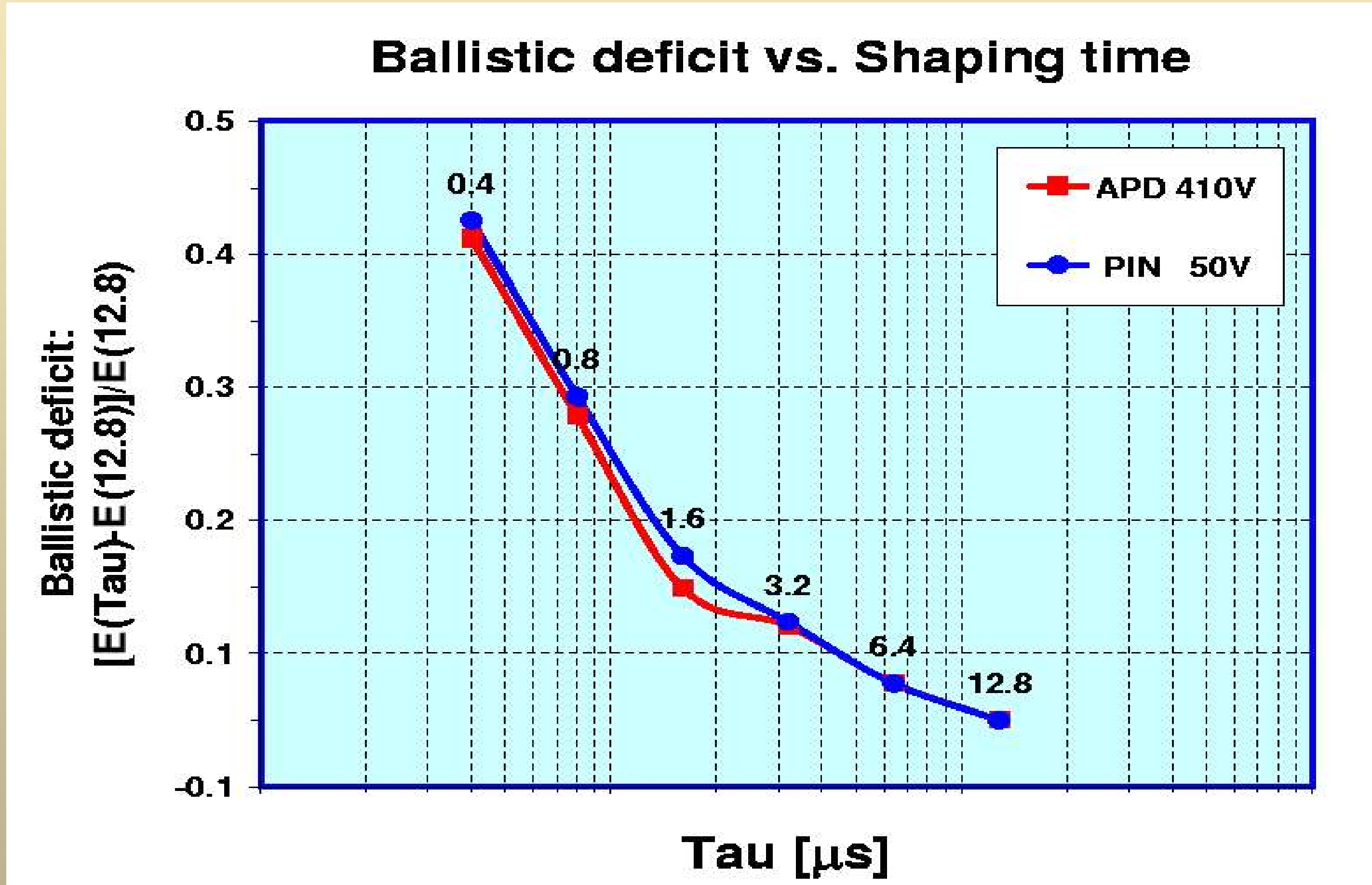
Compare APD-data with data obtained for PIN-PD



Conclusions: *The electric noise for APD is less than half of the noise for PIN-PD;*
It is smallest & has the least variation for $U_{APD} \approx V_B$;
Optimal shaping times for APD & PIN-PD are similar;

Noise & Ballistic Deficit measurements – the Ball. Deficit:

Measured for PIN-PD and APD using E_α =5.147MeV (AMR33)



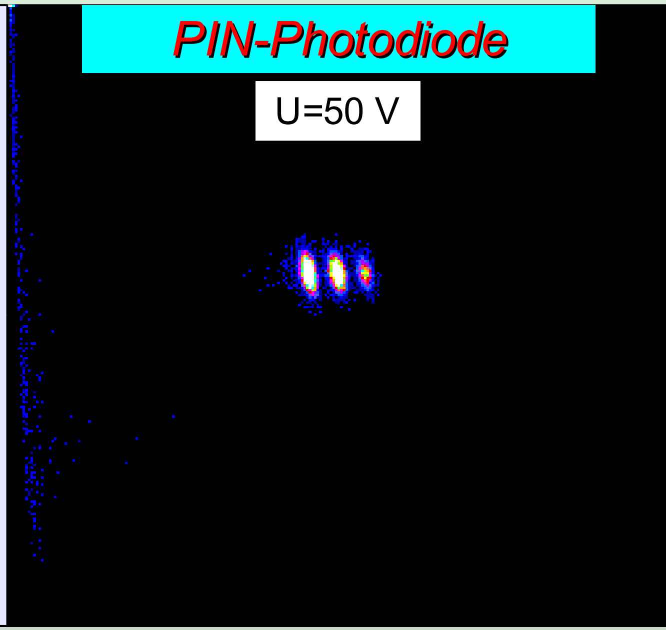
Conclusions: *Avalanche-PotoDiode and PIN-PhotoDiode give similar Ball. Def. ----->*
Part. Discr. method applied in VXI electronics can be used in DSP solution

3d) PID-vs-Energy spectra for CsI detectors using PIN-PD and APD readout:

DIAMANT electronics: 1st+2nd stage PreAmp with a Part. Discr. Unit (τ_{peak}= 10 μs)

Gain(PDU): x8

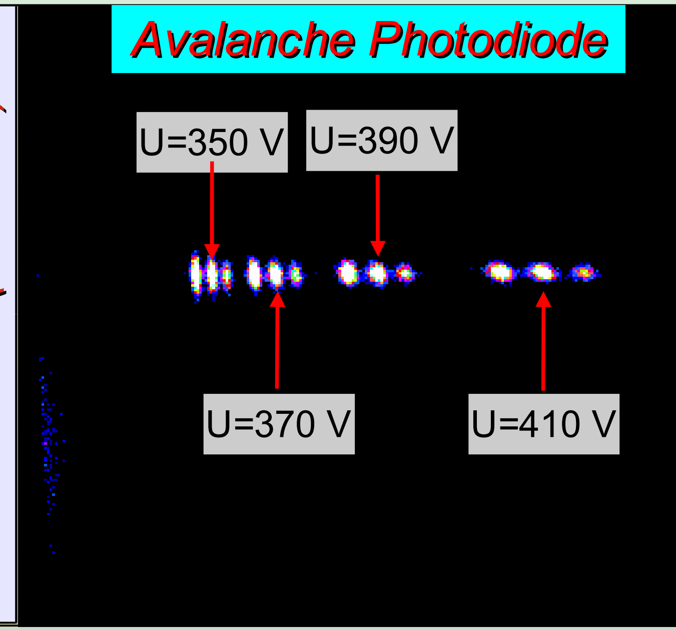
Particle ID (arb. unit)



Energy [arb. Unit]

Gain(PDU): x1

Particle ID (arb. unit)



Energy [arb. Unit]

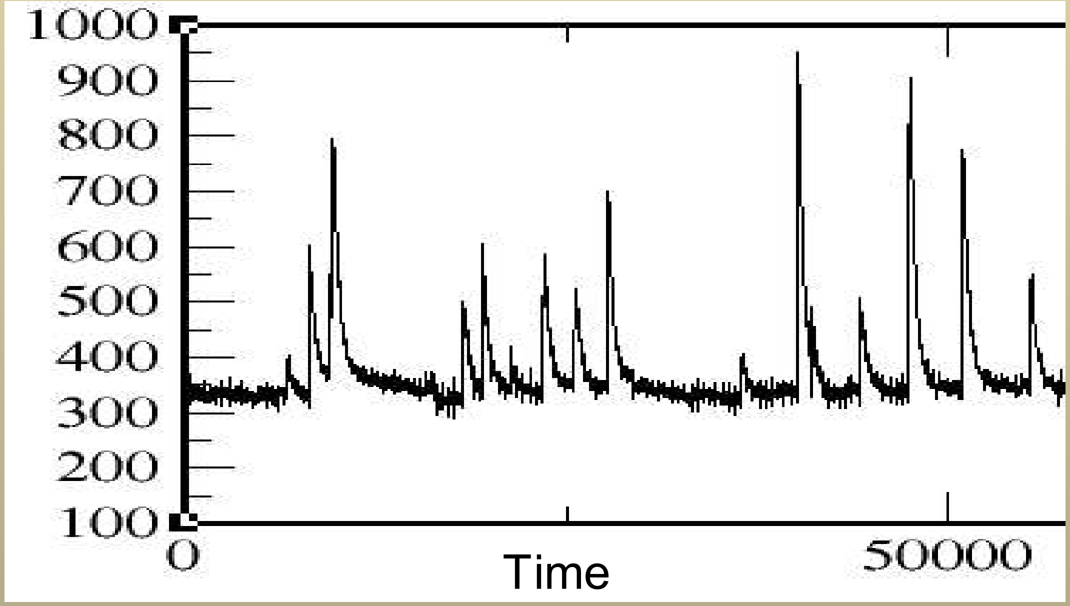
Conclusions: Avalanche-PD should give much better part. separation, as $FWHM_{PID}$ is much better for APD than for PIN-PD, especially for $U_{APD} \approx V_B$!

4. Software developments for Digital Signal Processing

a) Studies on particle discrimination using trace data from a PIXIE-16 DSP electronics for CsI+pin-PD detectors (XIA-based system @ iThemba LABS, South Africa)

Aim: *determine methods and parameters for obtaining the best particle discrimination with DSP electronics using trace data from a*

Example spectrum of digitally sampled DIAMANT signals



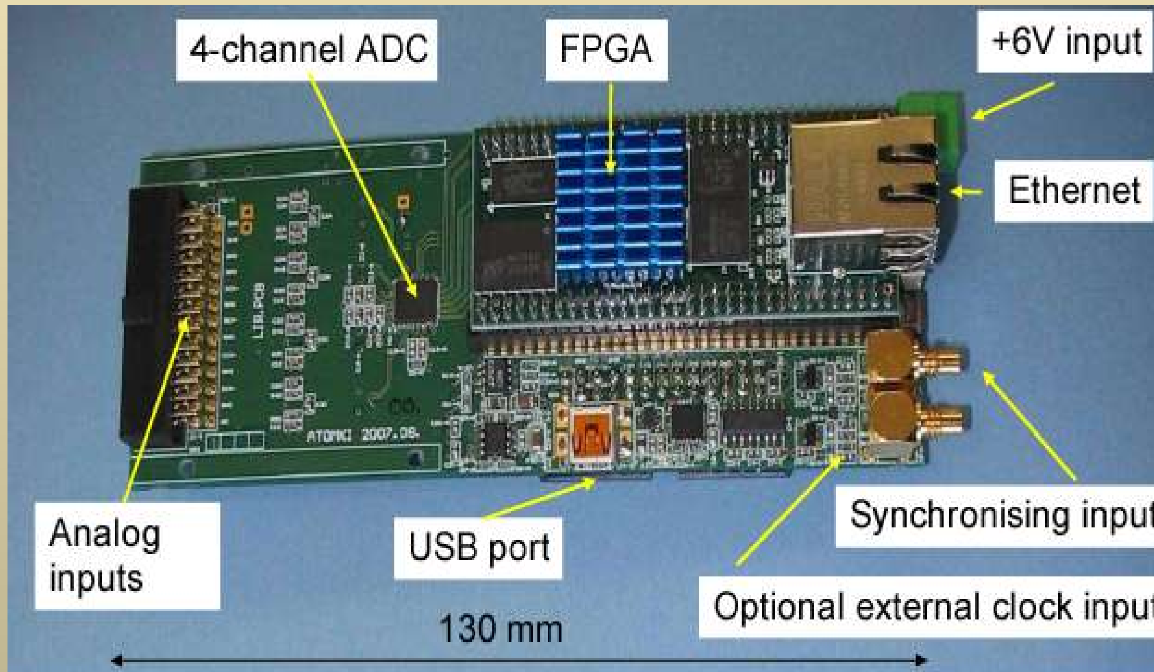
Software developments:

digital filtering;
baseline restoration;
generation of PID-vs-Energy sp., etc.

Work still in progress!

b) DSP developments for new APD-based CsI detectors:
- using ATOMKI's LIR card (Virtex4-based system; 50 MHz sampling)
- using the DSP module under development for EXOGAM2

The ATOMKI solution: the LIR module based on Virtex-4 FPGA (dev.'d earlier)



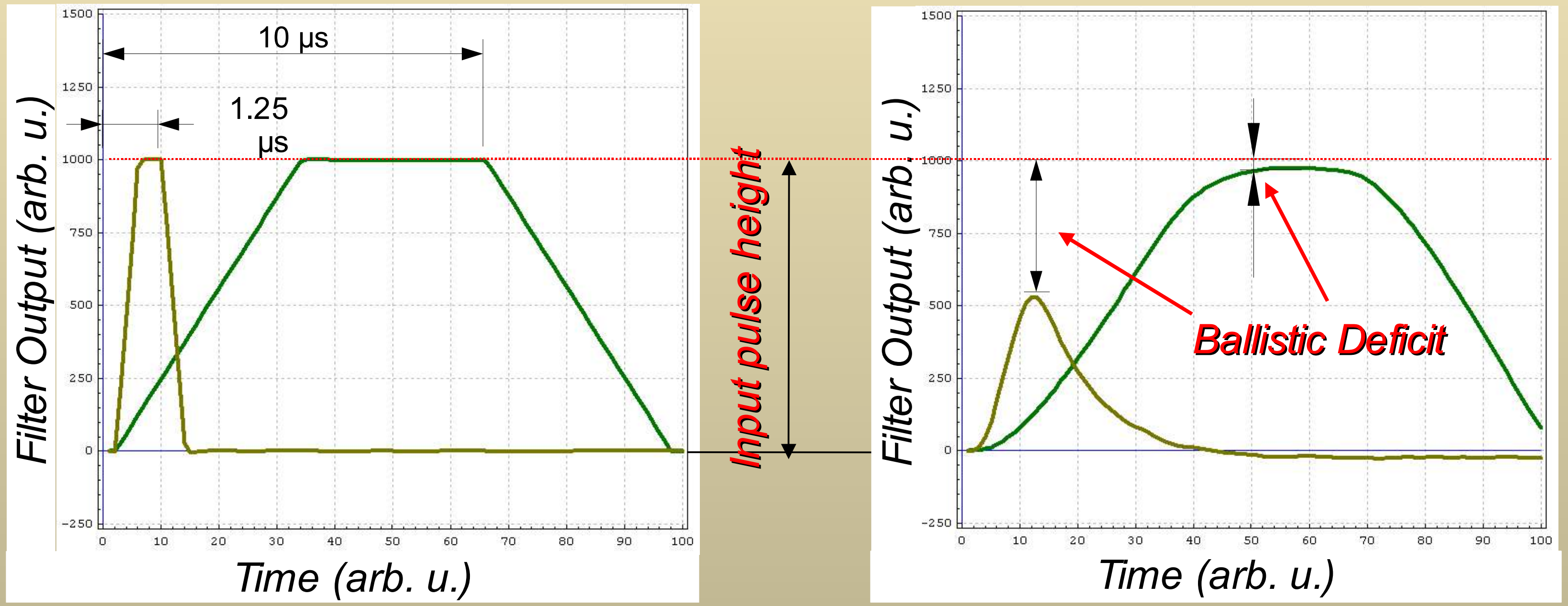
Featuring:

- 4 independent ADC channels
- FPGA-based DSP
- 1 Gbit Ethernet connection
- 6V / 1A (6W power)

Implementation of the Ball. Def. method for particle discrimination with DSP

Outputs of digital trapezoidal filters for an input signal with $T_{rise} \approx 0$ μs

Outputs of digital trapezoidal filters for an input signal with $T_{rise} = 3.6$ μs



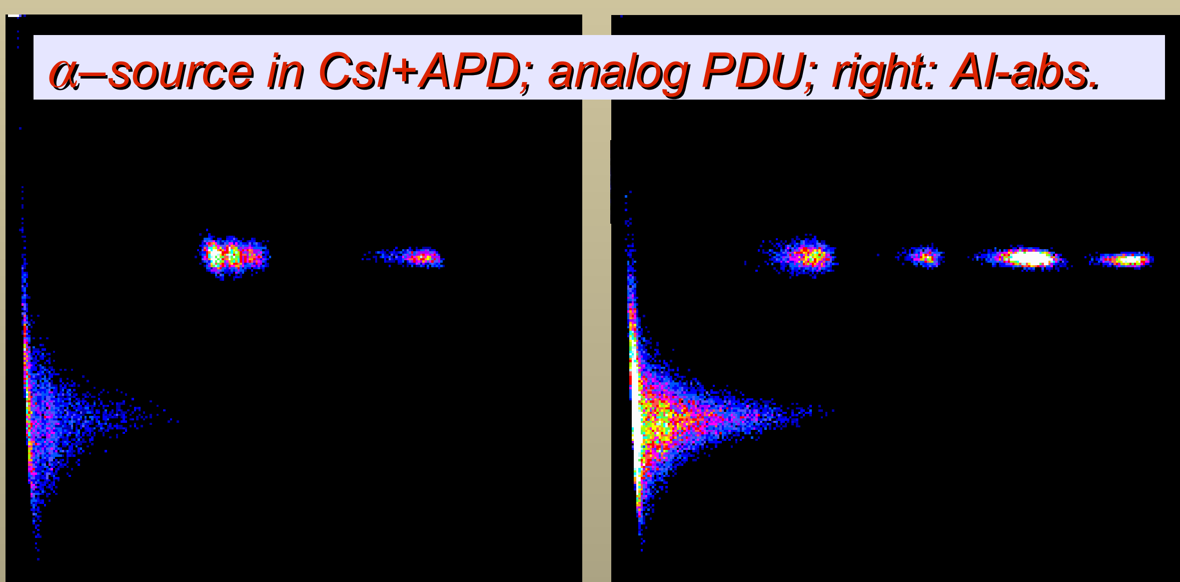
The same peaking times, T_{peak} = 1.25 μs and T_{peak} = 10 μs are used, as in the analog PDU, to generate PID and Energy for the particles having different decay times (τ_{part}) of the scint. light.: BD = $f(\tau_{part}/\tau_{peak})$.

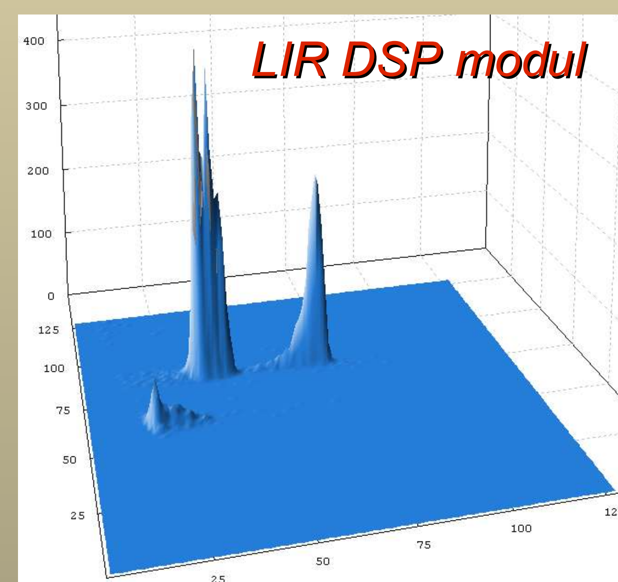
5. In-beam tests of CsI+APD detector with analog & DSP electronics

Aim: Investigate the low-energy particle separation limits; ((p-α), (α-))
[Old limit(VXI) to be improved: $E_p / E_\alpha \approx$ 2.1MeV / 4.5 MeV; measured FOM]

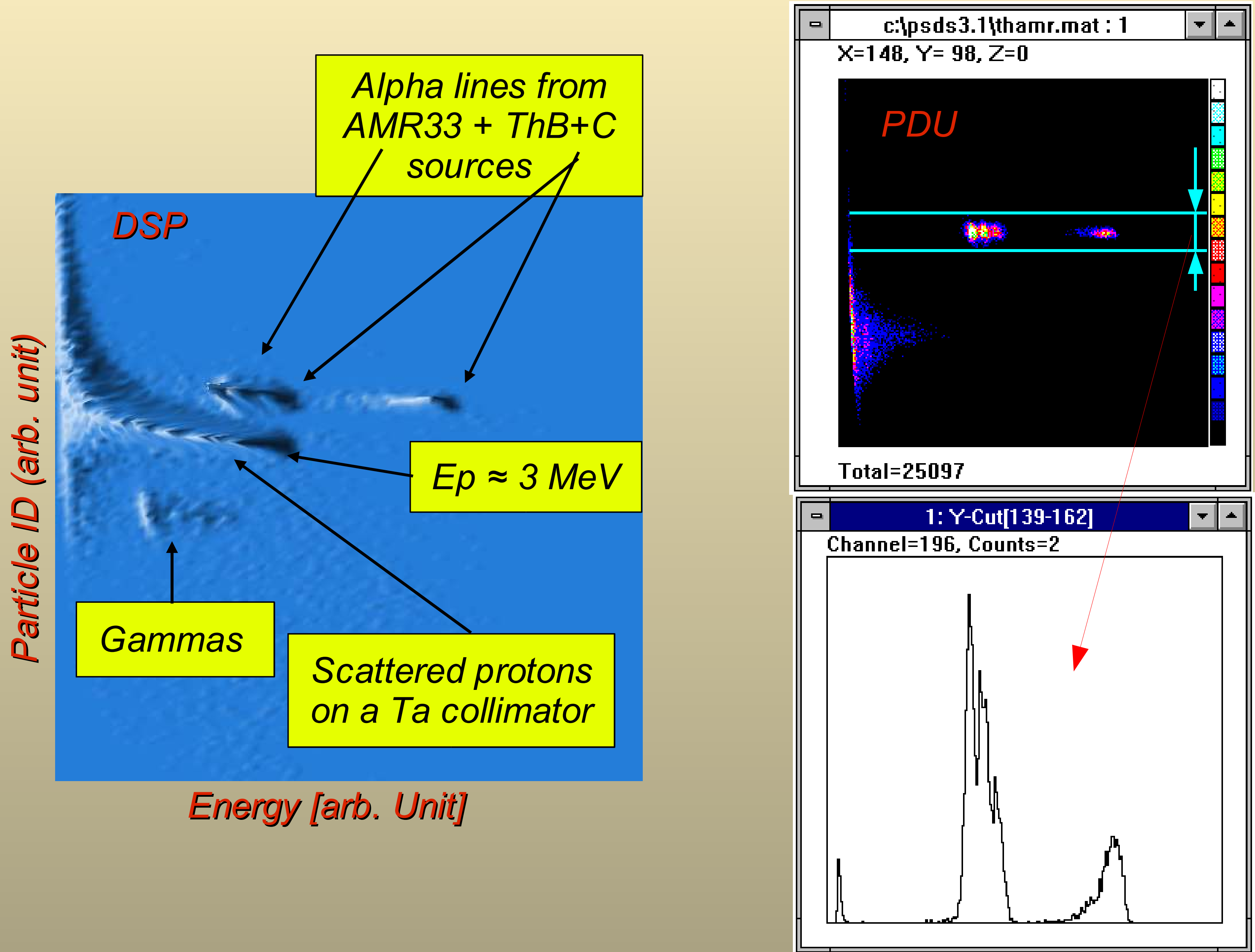
Method: Use low energy protons/alphas & high energy gammas:
α–sources + absorbent foils / cyclotron beams

Experimental setup: (In-beam test done last week !)
ATOMKI cyclotron: E_{proton} = 3.3 MeV; use elastic scattering / (p,α) reactions
CsI+APD test-detector (temporary optical coupling)
Analogue PDU electronics (prototype for VXI)
LIR modul of DSP electronics (ATOMKI) set with VXI-style parameters


α–source in CsI+APD; analog PDU; right: Al-abs.



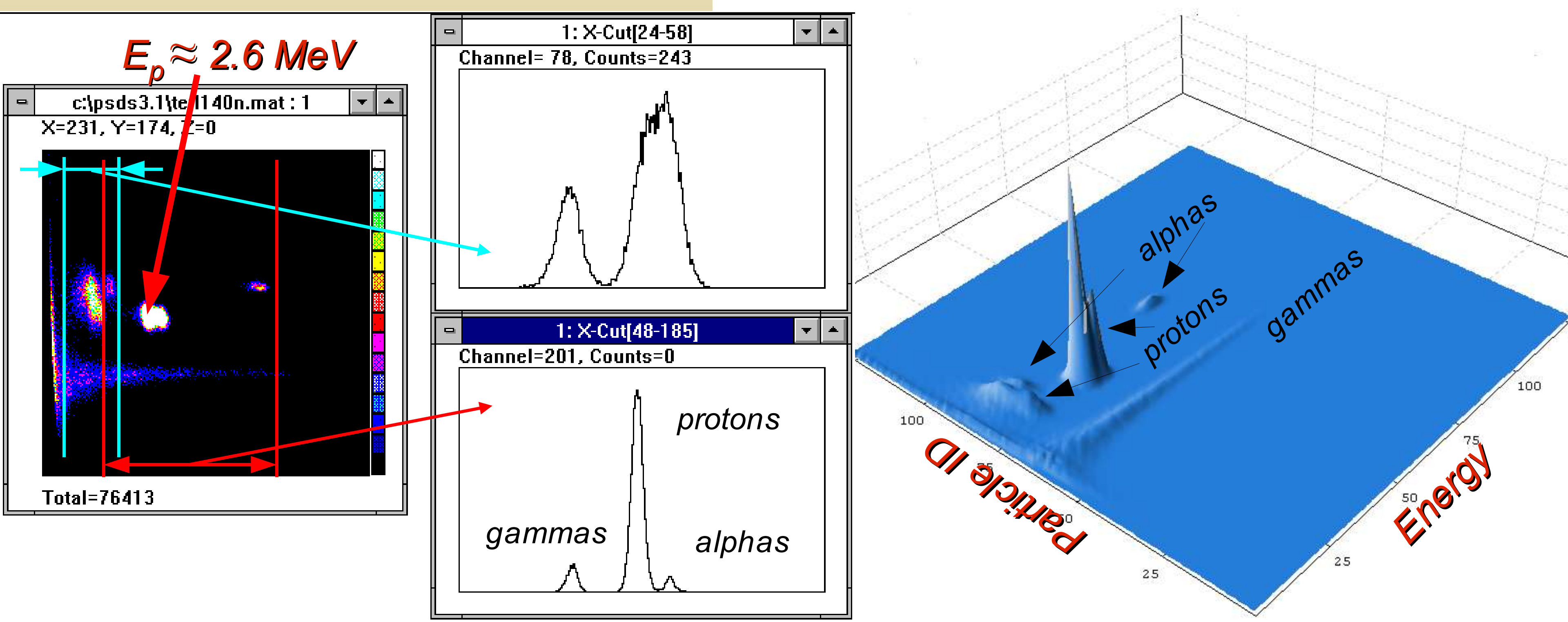
Testing the Low-energy particle separation limit:
First Energy & PID spectra obtained with LIR-DSP for a CsI+APD detector



First in-beam results with a CsI+APD detector:

Exp. Details: E_p = 3MeV; θ = 140°; Target: Teflon-tape $(C_2F_4)_n$;

Analog Part. Dicr.: prototype PDU *LIR DSP-module*

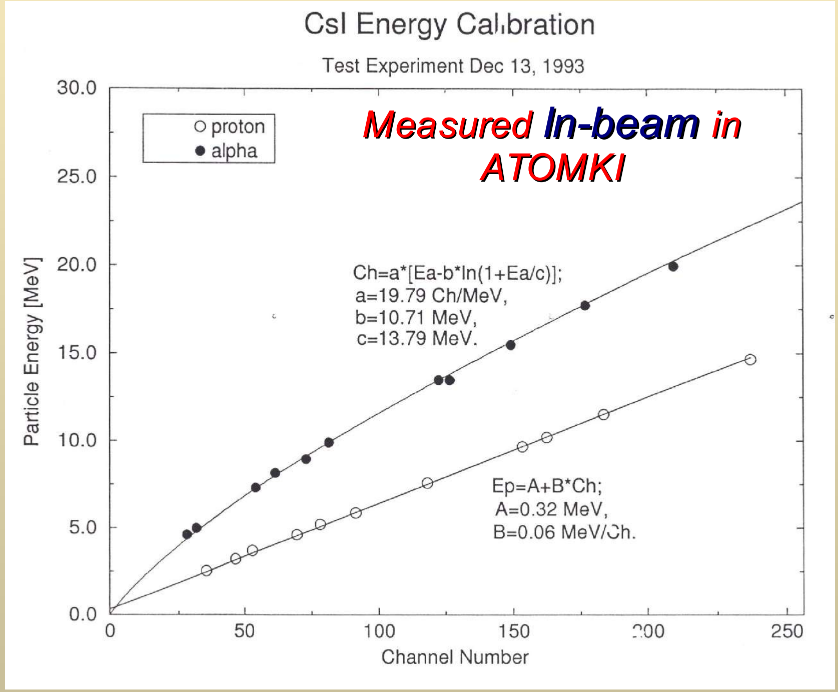


Energy & PID spectra show, that the low-energy part. discr. limit has improved a lot: $E_p / E_\alpha \approx$ *1.2 MeV / 3.2 MeV*

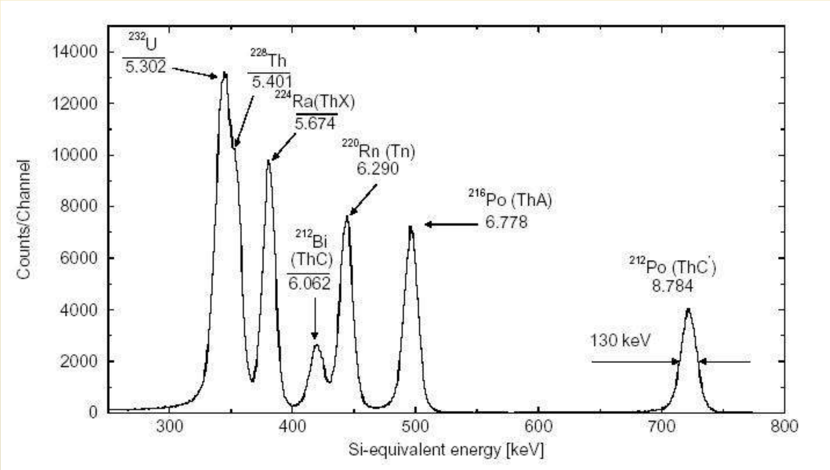
(estim. from kinematics + CsI energy calibration)

CsI calibration: Doppler correction, reaction mech. studies, etc.

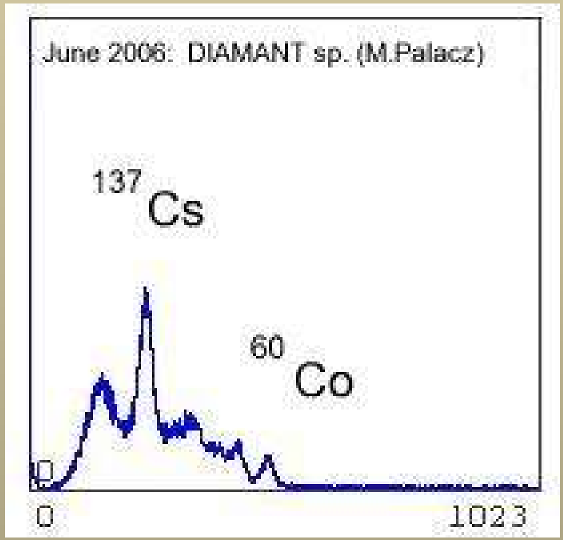
In-beam,



with α-sources



with γ-sources:



Problems:

In-beam - needs beam-time, cost

Sources: needs ^{232}U or ^{228}Th α-sources on target loader

γ-sources in target position (needs action from GANIL)

Based on comparative α and γ calibrations: [D. Horn et al. NIM A420(1992)273]

Light yield vs E:

$$L = E - a \cdot \ln\left|1 + \frac{E}{a}\right| \qquad a = bAZ^2 \quad a_p = 0.326 \quad a_\alpha = 5.216$$
$$b = 0.326 \pm 0.003$$

Summary & Outlooks

Mechanical upgrade of the DIAMANT chamber: *(practically done)*

good vacuum, new cabling for better grounding/shielding ----> Reliable operation

Development and tests of CsI detectors with APD readout:

New prototype PreAmp dedicated to CsI & APD detectors

Plan: replace the present PA-s with the new; Next: Production phase

Source and in-beam tests of CsI+APD shows its superiority vs. PIN-photodiodes

Further tests needed: temperature dependence /treatment of HV

DSP developments for DIAMANT (feasibility studies - FP7):

Tests of particle discrimination algorithms for CsI+pin-PD type of DIAMANT detectors using data from a DSP electronics (installed at AFRODITE)

Implementation and successful test of Ball. Def.-based part. discr. method

using the Xilinx Virtex-4 FPGA developed at ATOMKI

Preliminary tests show its applicability; further tests needed for optimization!

The ralization of these planned upgrades are subject to financing:

even though DIAMANT would become fully compatible with either EXOGAM2 or AGATA DAQ systems!

Thanks for support from EXOGAM-2 FP7, TÁMOP (HU), & NIH (SA-HU TéT collaboration)

Financial, personnel (open) questions

a) *DIAMANT group applied for Hung. Res. Fund: under process (requested support for EXOGAM2+DIAMANT related investments: ~ 250 kEUR)*

b) *Students involved in DSP development works (PhD + 2 undergraduates)*

c) *Planned works: simulations for DIAMANT+ AGATA (students)*