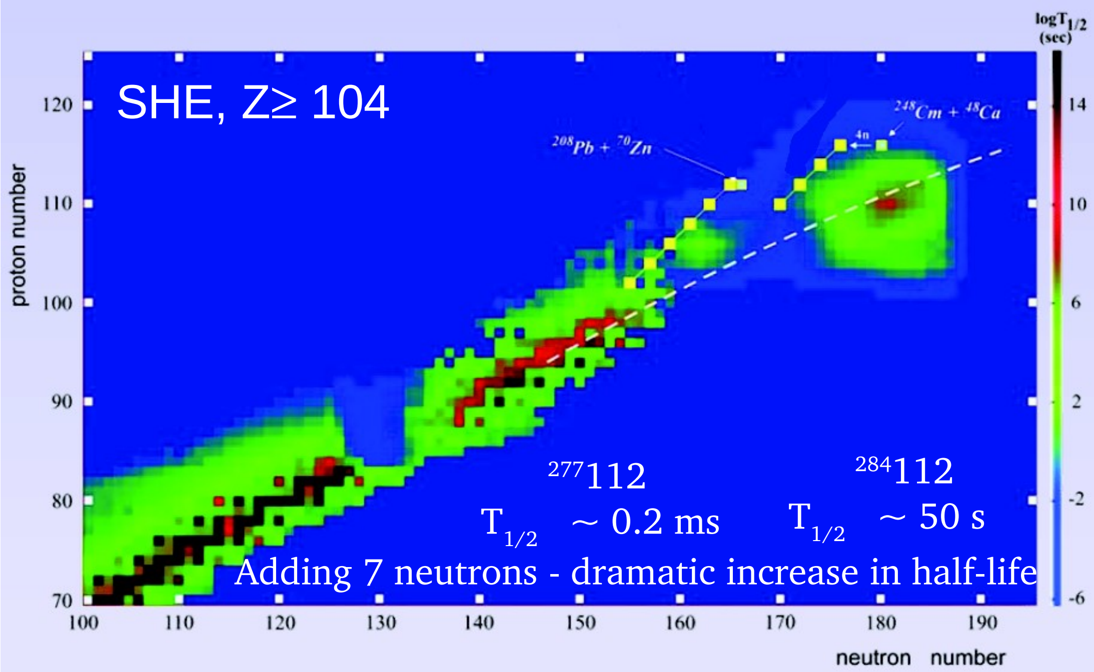
# Outline

- Motivation
- Three generations of experiments
- Experimental setup – detection system and electronics
- Preliminary results
- Conclusions

# Where is the limit of SHE?

***Theory***

- 1957: Scharff-Goldhaber – suggested "magic island" around Z=126 and N=184
- 1966: A. Sobiczewski, F.A. Gareev, B.N. Kalinkin – magic numbers: Z=114, N=184
- 1966: W. D. Myers, W. J. Świątecki – another magic numbers: Z=126, N=184

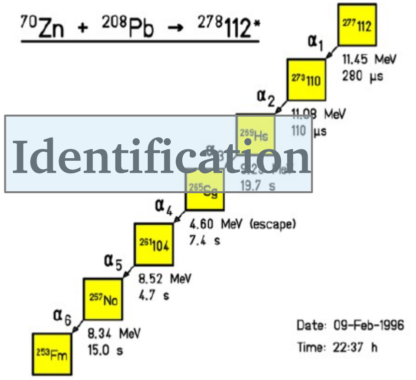



***Experiment***

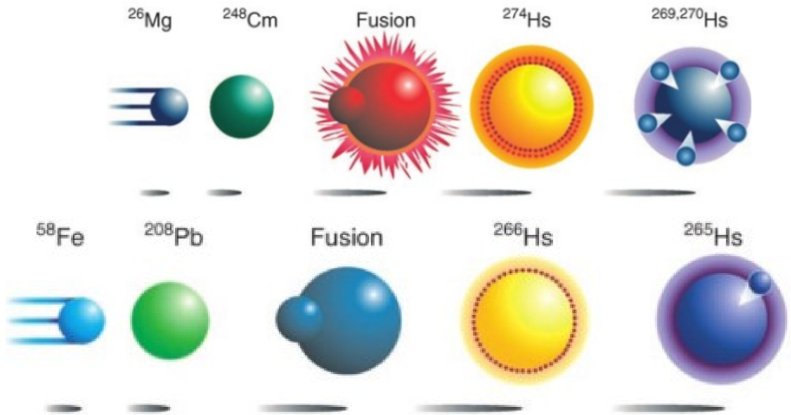
- LBNL, Berkeley: Z=106
- GSI, Dramstadt: Z=107, 108, 109, 110, 111, 112
- JINR, Dubna: Z=104, 105, 106, 107, 113, 114, 115, 116, 117, 118
- RIKEN, Tokyo : Z=113

# Classical approach to the SHE creation

**Identification**




- 1950s: beams heavier then alpha partciles



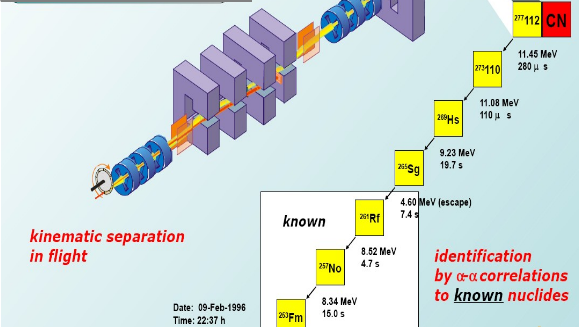

## Hot fusion (Cf, Pu actinide targets)

- $E^{*}=30\text{-}50$ MeV[1)]
- 3-5 neutrons emitted before SHE reaches ground state
- e.g.: $^{48}Ca+^{249}Cf \rightarrow ^{297}118 \rightarrow ^{294}118+3n$

## Cold fusion (Pb, Bi targets)

- $E^{*}=10\text{-}15$ MeV[2,3)]
- 1 neutrons emitted end SHE reaches ground state
- e.g.: $^{70}Zn+^{209}Bi \rightarrow ^{279}113 \rightarrow ^{278}113+1n$

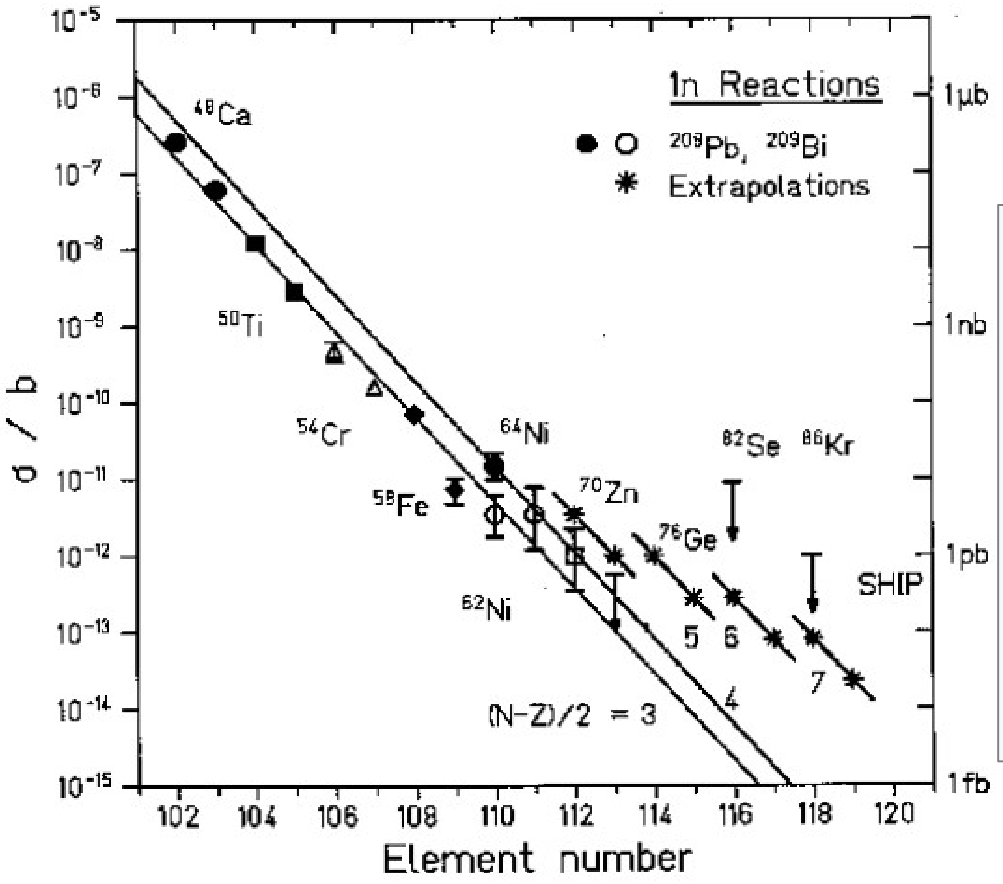
**Filter:**




**Conclusion: carefull choice of collision energy and projectile target combination**


1. *Y. Oganessian et al., Phys. Rev. C74 (2006) 044602.*
2. *S. Hofmann et al., Z. Phys. A354 (1996) 229.*
3. *K. Morita et al., Journal of the Physical Society of Japan,81(2012)103201*

# Cross section data and extrapolated values for cold fusion reactions (1n-evaporation channel) [1]




**$\sigma_{ER}$=1.0 and 0.5 pico barn** *for production of* **Z=112**[1]**, 118**[2]**.**

- *Presently it is difficult to reach experimentally such low cross sections (limited by intensity of ion sources and rejection ratios of ER filters).*
- *To synthesize neutron rich SHE elements, radioactive ion beams (RIB) facilities can be considered, but we are still very far from using such facilities to reach the neutron closed shell N=184 (due to too low cross section for the production of neutron-rich fragments by RIB).*


1. Hofmann et al., Eur. Phys. J. A14 (2002) 147.
2. Yu. Ts. Oganessian et al., Phys. Rev. C74 (2006) 044602.

# Alternative reaction mechanism for Super and Hyper Heavy Elements (SHE/HHE) production

**Massive transfer (multi nucleon transfer) reactions between heavy projectile (Au) and heavy target nuclei (Th) while e.g. nuclei are orbiting.**

**Remarks for the mechanism:**

- **Here, in contrary to the complete fusion a spectrum of SHE will be wide (in Z and in velocity)**
- **A „classical" velocity filter can not be utilized**
- **$^{197}Au$ projectile can pickup large fragment of $^{232}Th$:** $Z_{SHE} \approx 45+79=124$ ?

Let's **Nature** to select the most appropriate transfer to produce SHE

# Three generations of our experiments for SHE search.
## Cyclotron Institute, Texas A&M University, 2002 – up to now

### I. ***BIGSOL experiments***

*The large-bore 7-Tesla Superconducting Solenoid –* ***BigSol*** *(reaction products velocity filter)*

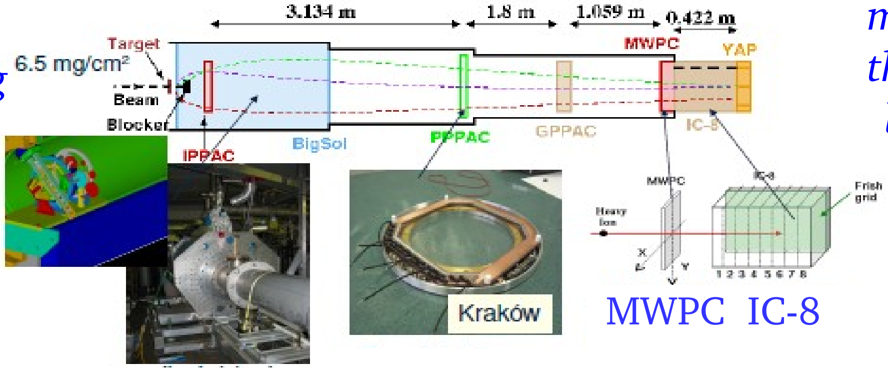
$^{136}$Xe,$^{172}$Yb,$^{198}$Pt(15 A.MeV) + $^{238}$U

$^{84}$Kr, $^{172}$Yb(15 A.MeV+$^{232}$Th

$^{238}$U(12 A.MeV) + $^{198}$Pt, $^{238}$U,$^{232}$Th

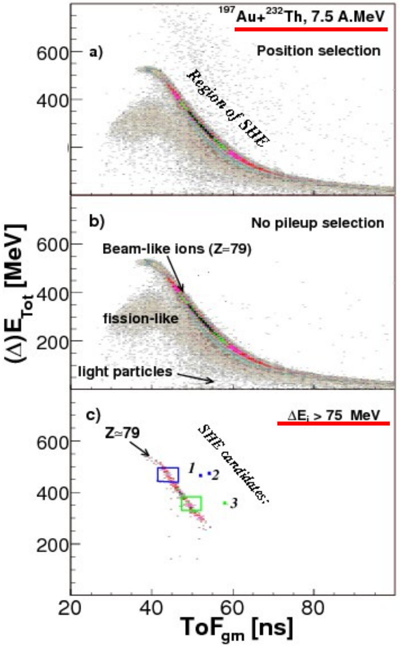
$^{84}$Kr(24.8 A.MeV+$^{232}$Th

$^{84}$Kr,$^{129}$Xe,$^{197}$Au(7.5 A.MeV+$^{232}$Th




*magnetic field parallel to the ER velocity vector – a large angle acceptance*

**Fall 2006 measurements:**
**$^{197}$Au(7.5 A.MeV) + $^{232}$Th**




*M. Barbui et. al.., Int. Journal of Modern Phys. E18 (2009) 1043*
*M. Barbui et al. Journal of Phys., 312 (2011) 082012*
*M. Barbui et al. AIP Conf. Proc. 1336 (2011) 594*
*T. Materna et al. In: Progress in Research April 1, 2003-March 31, 2004, p.II-17, http://cyclotron.tamu.edu/publications.html*

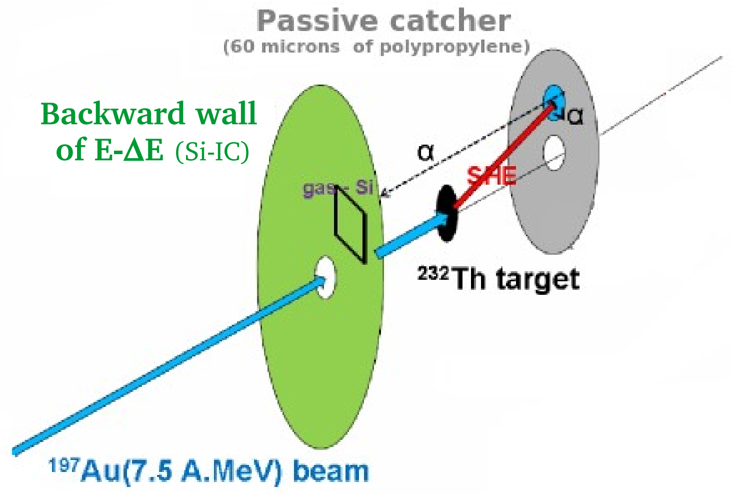
**Experiment was discontinued due to our idea has changed how to attack the problem.**

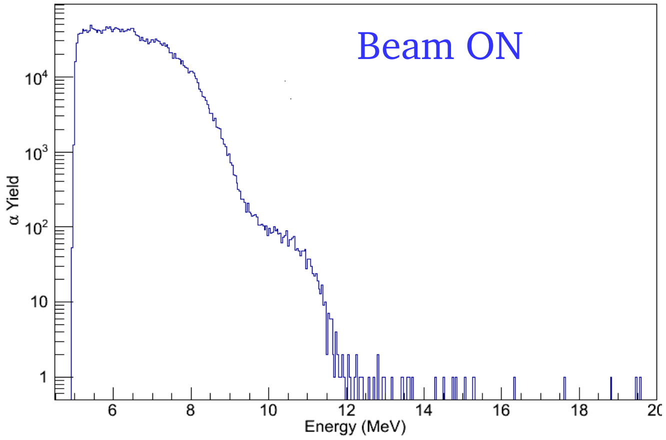
# Three generations of experiments …

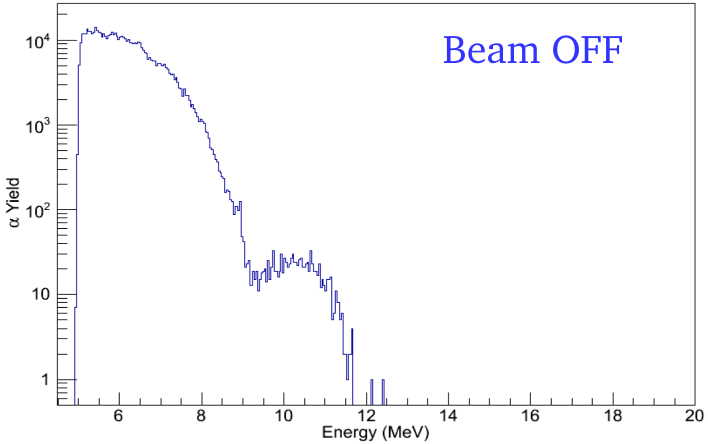
## II. *Passive catcher experiments – a simple system*

Search for alpha emitting SHE through implantation and decay of recoiling reaction products on a downstream catcher foil.

Determine lifetimes from growth and decay observations in beam and out of beam




Observed alpha particle decay energy distributions, beam-ON(left) and beam-OFF (right).

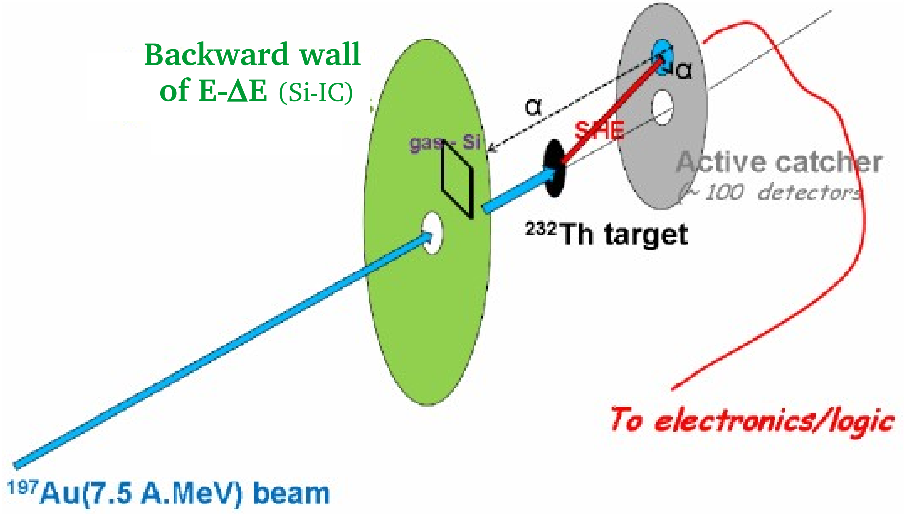
The backward wall of E-ΔE detectors detected signals of α particles with $E_\alpha$ >14 MeV.

However, it was impossible to exclude another emitters of α's then SHE

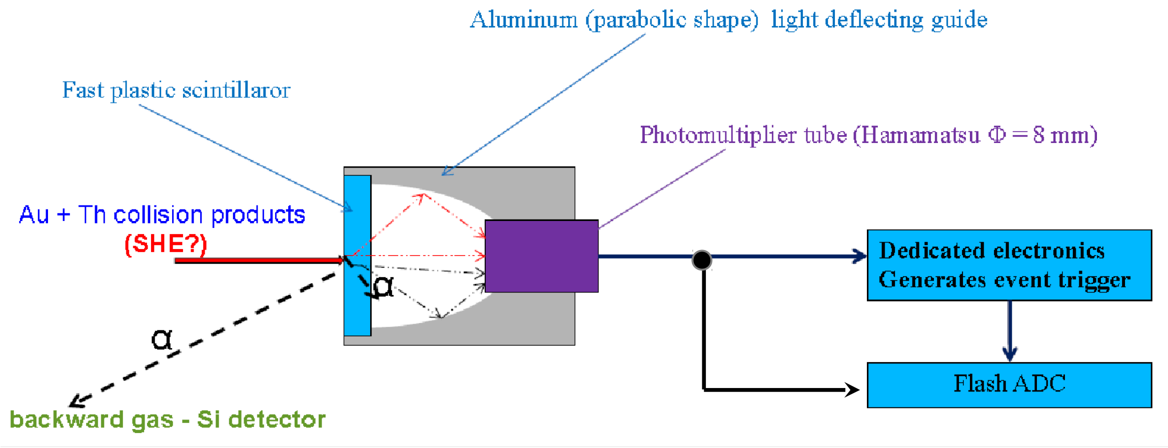
# Three generations of experiments …

## III. Active catcher experiments (starting 2012)

### Schematics of detection setup




### Active catcher detection unit




**Deposited heavy fragment within selected energy window**
**in coincidence**
**with alpha particle (detected by E-ΔE detector or scintillator )**
**alpha decay takes place within selected time window.**

*Z. Majka et al., Acta Phys. Pol.* ***B****, Vol. 45 No 2 (2014) 279.*

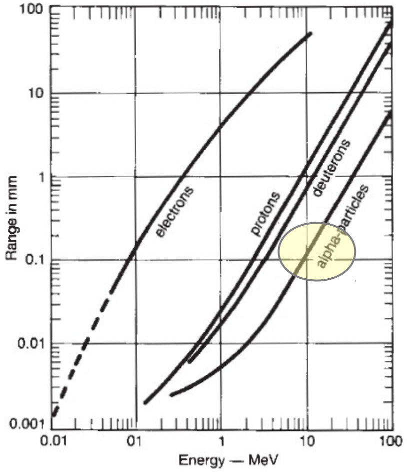
# Details of scintillator

| | BC-418 |
|---|---|
| **Scintillation Properties** | |
| Light Output, %Anthracene | 67 |
| Rise Time, ns | 0.5 |
| Decay Time (ns) | 1.4 |
| Pulse Width, FWHM, ns | 1.2 |
| Wavelength of Max. Emission, nm | 391 |
| Light Attenuation Length, cm* | NA** |
| Bulk Light Attenuation Length, cm | 100 |
| **Atomic Composition** | |
| No. H Atoms per cc ($x10^{22}$) | 5.21 |
| No. C Atoms per cc ($x10^{22}$) | 4.74 |
| Ratio H:C Atoms | 1.100 |
| No. of Electrons per cc ($x10^{23}$) | 3.37 |

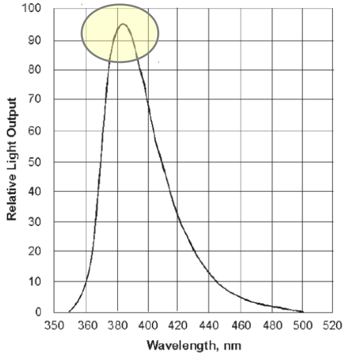
**General Technical Data –**

| | |
|---|---|
| Base | Polyvinyltoluene |
| Density [g/cc] | 1.032 |
| Expansion Coefficient (per°C,<67°C) | $7.8X10^{-5}$ |
| Refractive index | 1.58 |
| Softening Point | 70°C |
| Vapor Pressure | May be used in vacuum |
| Solubility | Soluble in aromatic solvents, chlorinated solvents, acetone, etc. Unaffected by water, dilute acids, lower alcohols, alkalis and pure silicone fluids or grease. |

Range of Atomic Particles in Premium Plastic Scintillator

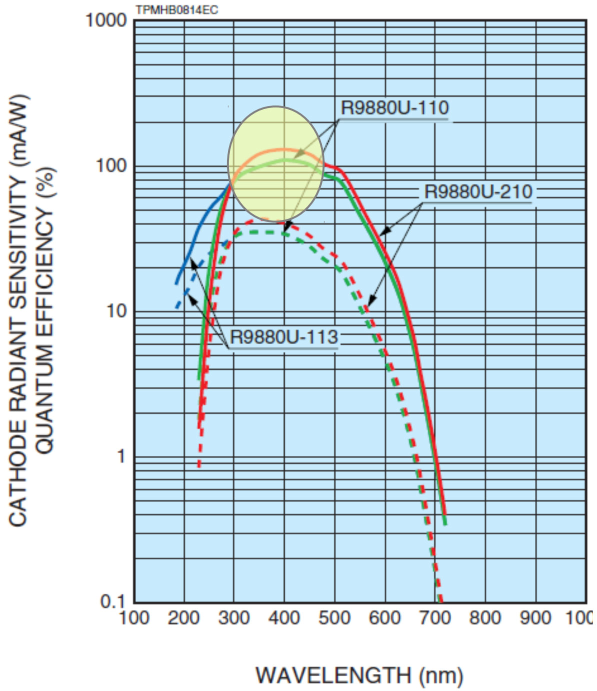


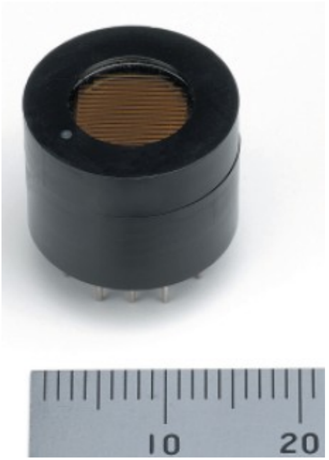

BC-418 & BC-420

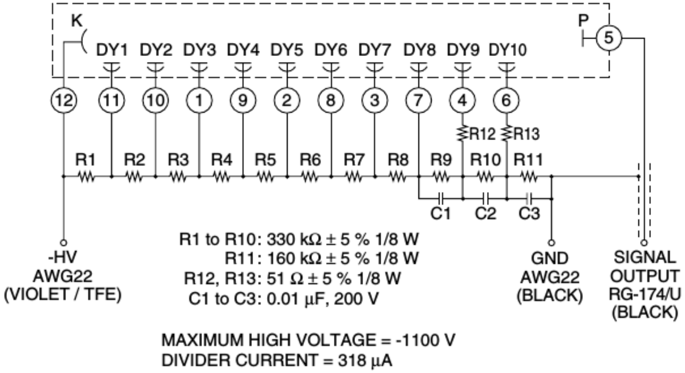


# Details of PMT

Figure 1: Typical Spectral Response



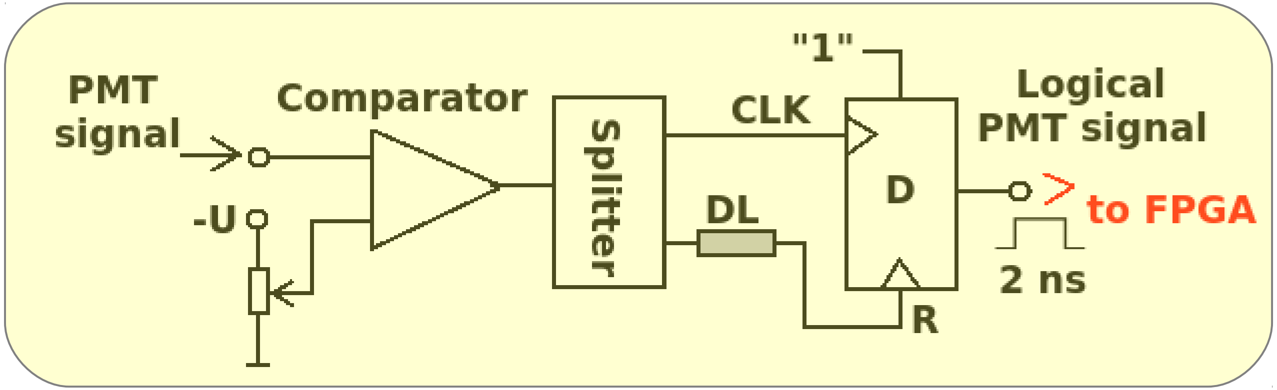




| Anode to Cathode Supply Voltage (V) | Anode Characteristics: Luminous Min. (A/lm) | Luminous Typ. (A/lm) | Gain Typ. | Dark Current (After 30 min) Typ. (nA) | Dark Current Max. (nA) | Time Response: Rise Time Typ. (ns) | Transit Time Typ. (ns) | TTS Typ. (ns) | Operating Ambient Temperature (°C) | Storage Temperature (°C) | Type No. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1000 | 100 | 400 | $2.0 \times 10^6$ | 1 | 10 | 0.57 | 2.7 | 0.2 | -80 to +50 | -80 to +50 | R9880U-01 |
| | 100 | 400 | | 1 | 10 | | | | | | R9880U-04 |
| | 350 | 1000 | | 10 | 100 | | | | | | R9880U-20 |
| | 80 | 210 | | 1 | 10 | | | | | | R9880U-110 |
| | 80 | 210 | | 1 | 10 | | | | | | R9880U-113 |
| | 100 | 270 | | 1 | 10 | | | | | | R9880U-210 |

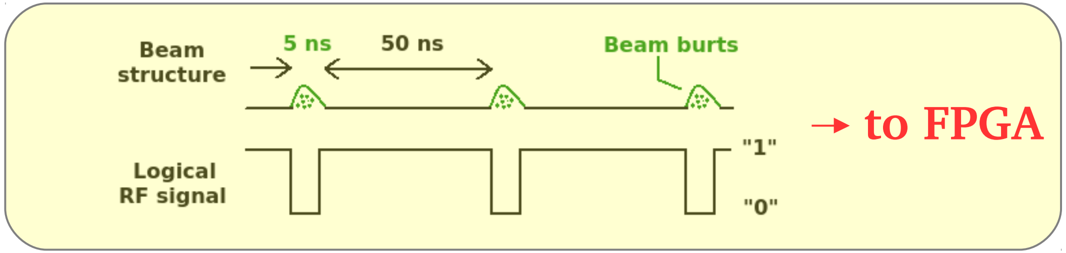
# Trigger generation

I. Conversion of PMT signals to fast logical ones
(the most complicated part)



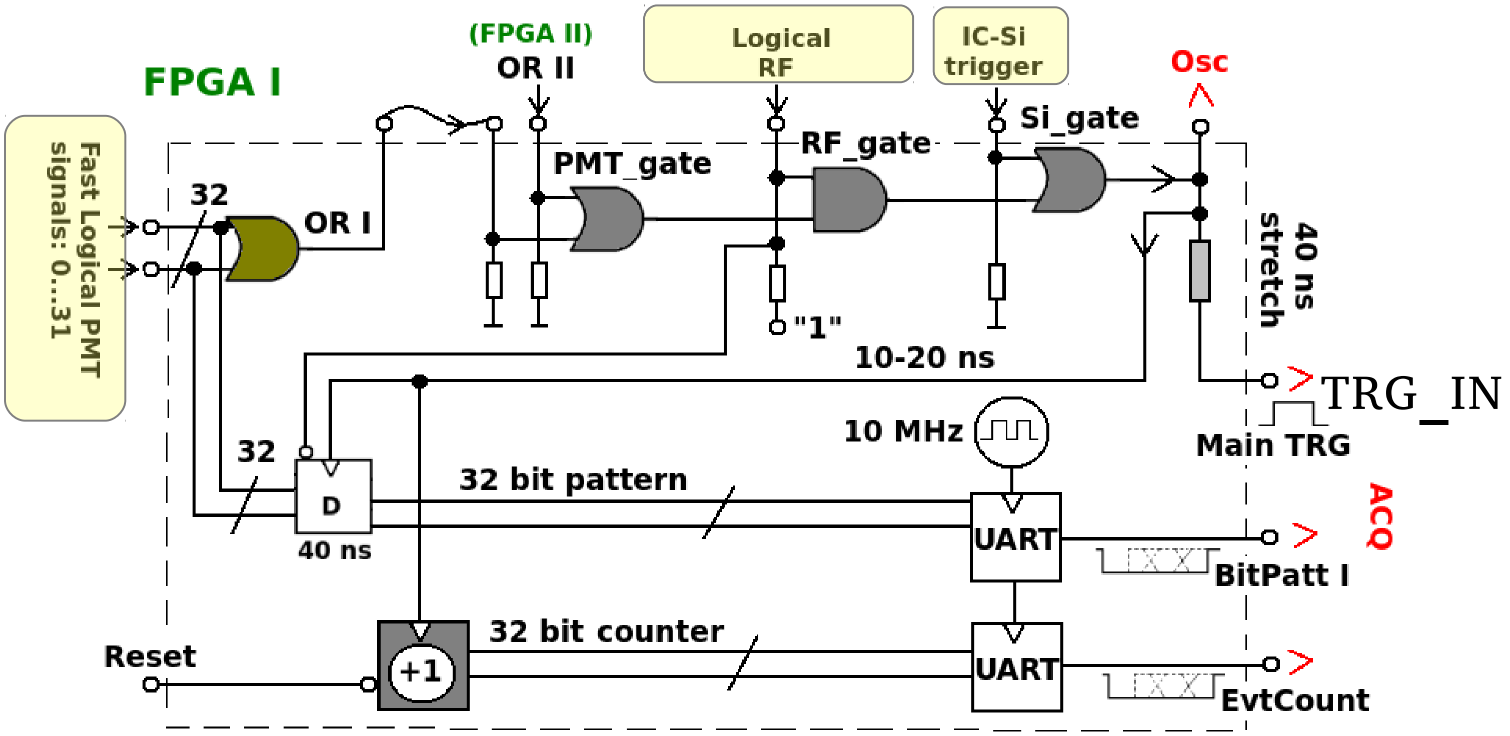

x 63

II. Convertion of RF signal (sinus) to negative logical one
(rather standard procedure)




In this philosophy we use electronics instead of spectrometer to eliminate the beam

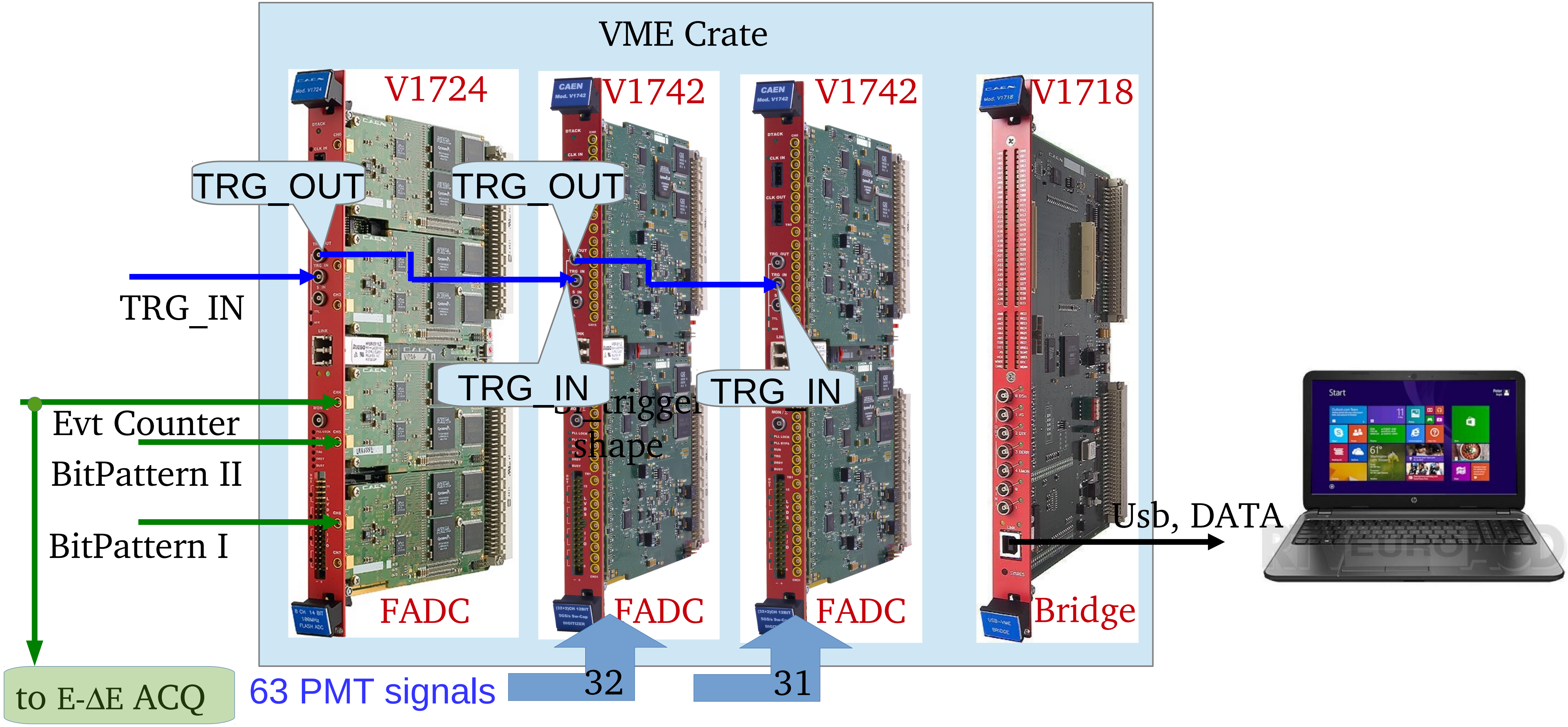
# Trigger logic, event counter




Logic constructed on FPGA served to produce main trigger from:

- *Logical OR for each of PMT pulses*
- *Logical AND for beam suppression*
- *Logical OR for E-ΔE (IC-Si) and PMT pulses*

# Acquisition of Active Catcher

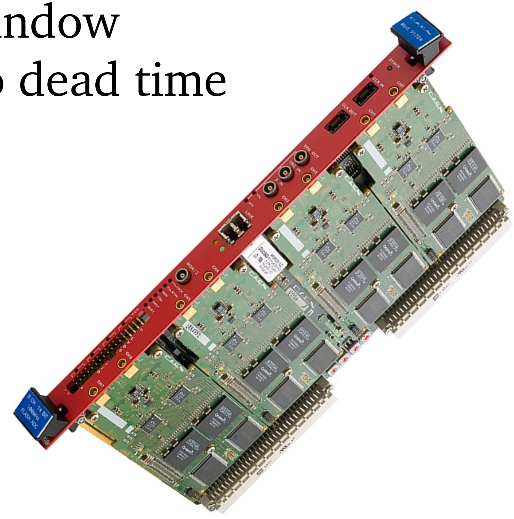


# ACQ hardware

To record bitpattern, event counter:

FADC V1724 (Caen)

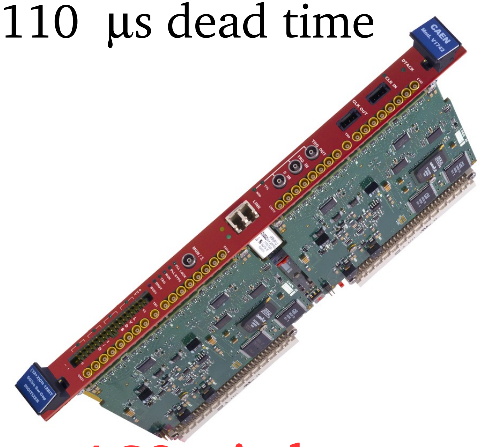
- 8 channels
- 100 Ms/s
- 100 MHz bandwith
- 10 or more μs acquisition window
- no dead time



To record pluse shape of PMT signals:

FADC V1742 (Caen)

- 32 channels
- 1-5 Gs/s
- 500 MHz bandwith
- 0.2-1 μs acquisition window
- 110 μs dead time



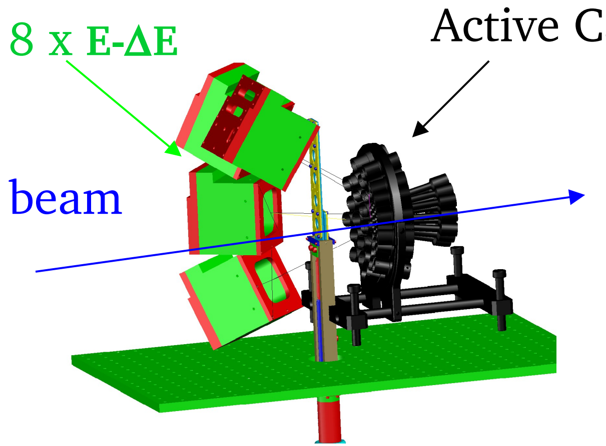
1 μs ACQ window was used

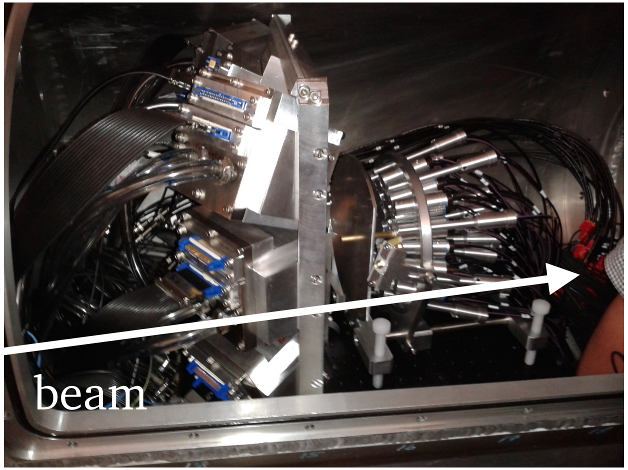
To transmit data to laptop:

Controller V1718 (Caen)

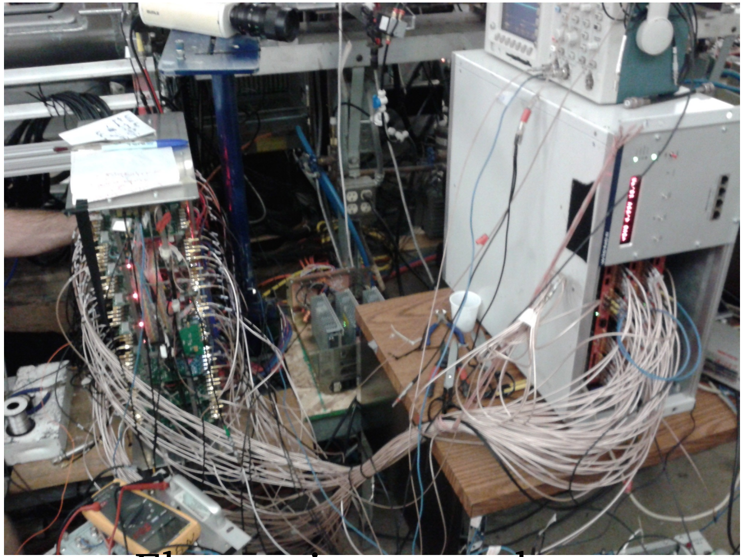
- 30 Mb/s data transfer rate
- VME Master
- VME Slave
- Cycles: RW, BLT, MBLT etc.
- Data width: D8, D16, D32, D64
- usb 2.0

# Some photos and schematics of detection setup

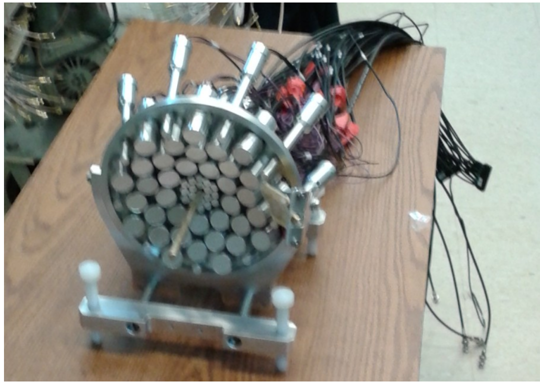



E-ΔE and AC mounted in the chamber



Electronics to produce trigger to ACQ, FADC

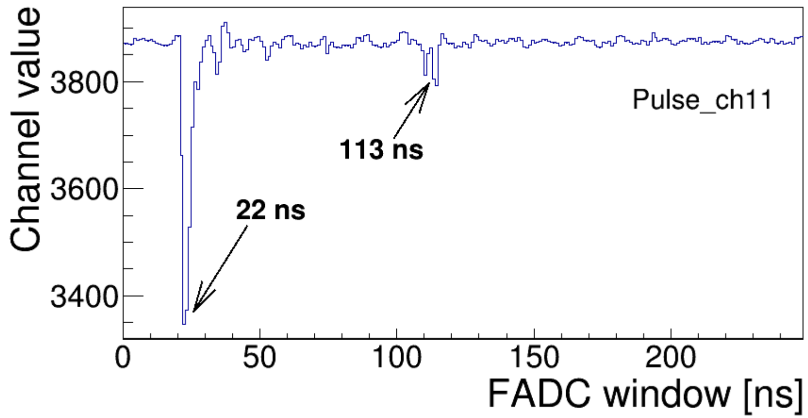


Front view of Active Catcher

**Setup summary:**

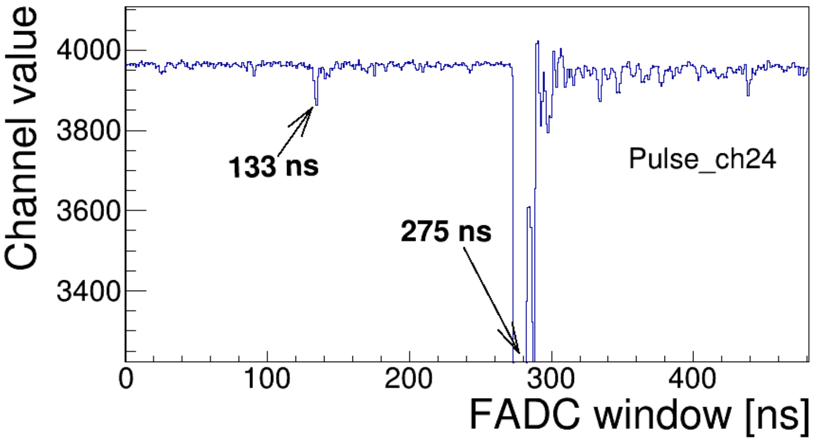
- Concave shape of the AC wall
- Scintillators covered by thin Al foil
- 63 PMT modules
- 12 HV, one to 4 PMT modules

# Preliminary results



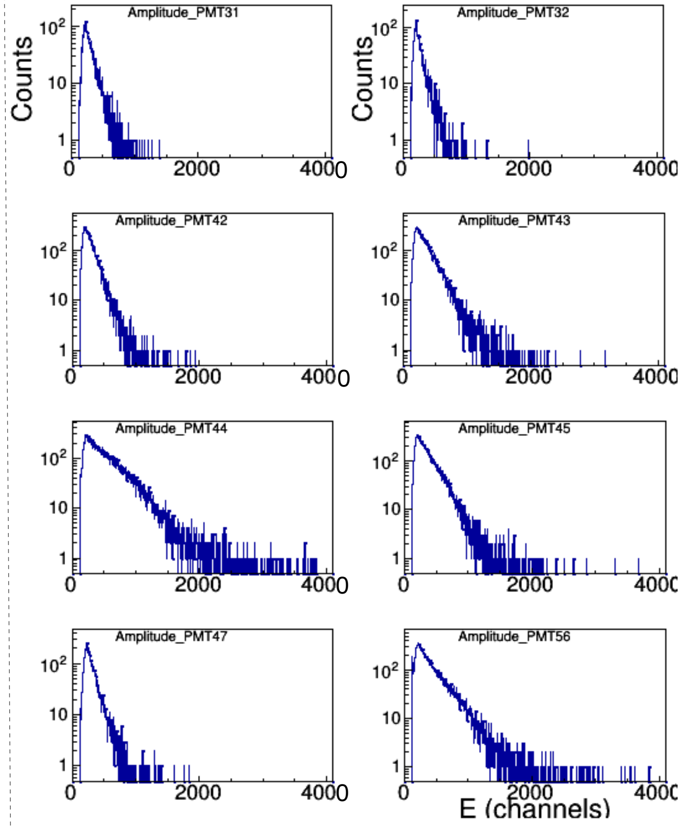

$E_\alpha$=9.90 MeV in E-ΔE

(113-22)/55=1.65, interesting case




$E_\alpha$=7.60 MeV in E-ΔE

(275-133)/55=2.58, large pulse can be due to SHE but it decays longer then 1 μs




Amplitude spectra of $^{252}Cf$ source, scintillator

# Conclusions

- High energy $\alpha$ are seen in backwards E-$\Delta$E detectors
- Very short scintillation pulses, 5 ns wide, are delivered by AC
- Active catcher events can be correlated with E-$\Delta$E events
- Some problems in trigger production were encountered
- Further improvements in trigger electronics are in progress
- Such a set-up should be able to detect very short life-times (>10 ns)
- Next experiment is planned to be on August 2015

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# Thank you for your attention!

View of a new campus of Faculty of Physics, Astronomy and Applied Computer Science of the Jagiellonian University, Krakow