Verification of Electromagnetic Calorimeter Concept for the HADES spectrometer

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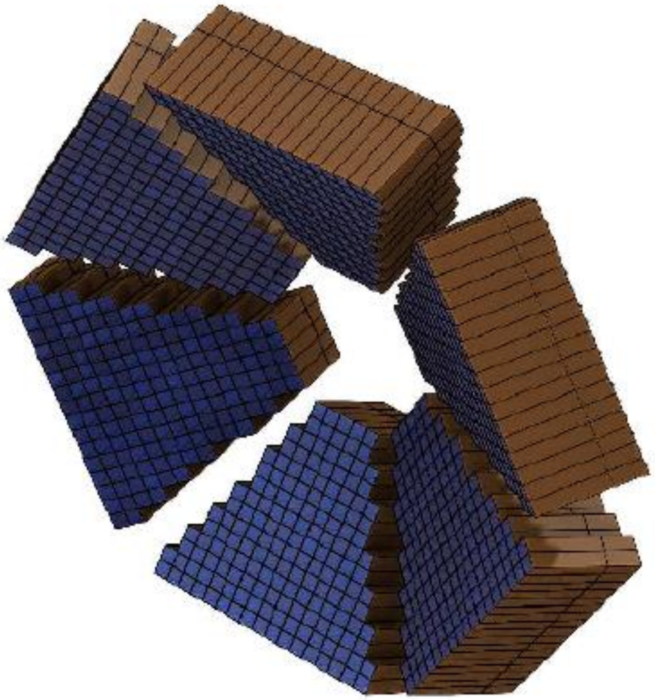
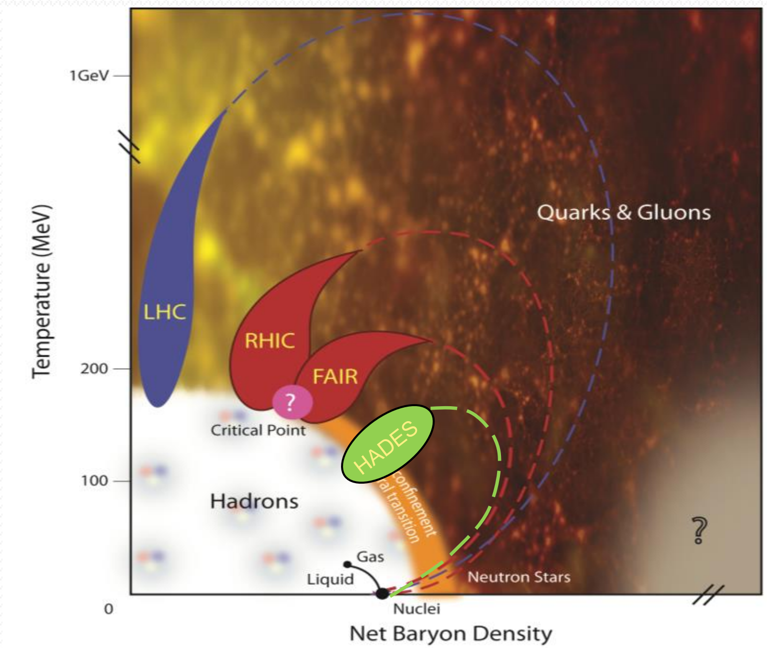
Outline

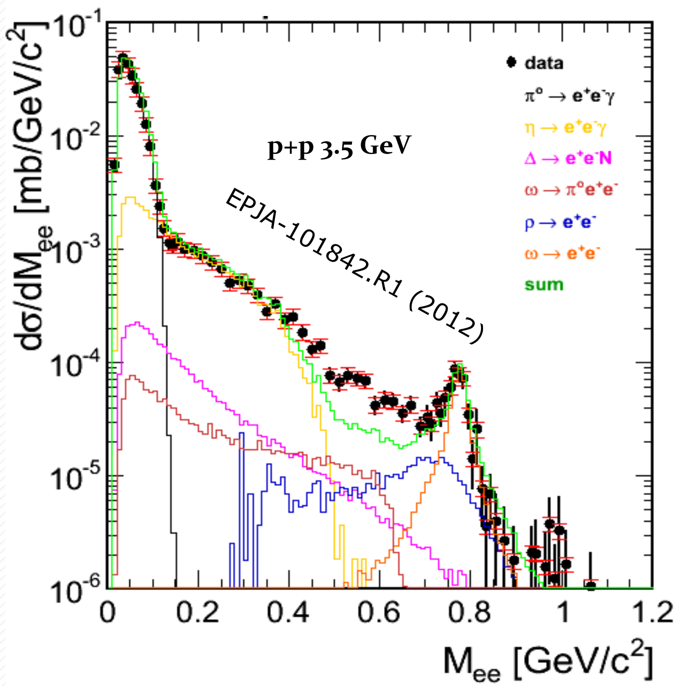
– Physics motivation
– Calorimeter module layout
– Front-end electronics
– Previous beam tests
– MAMI Mainz and experiment layout
– Energy resolution studies
– Energy leakage for different beams



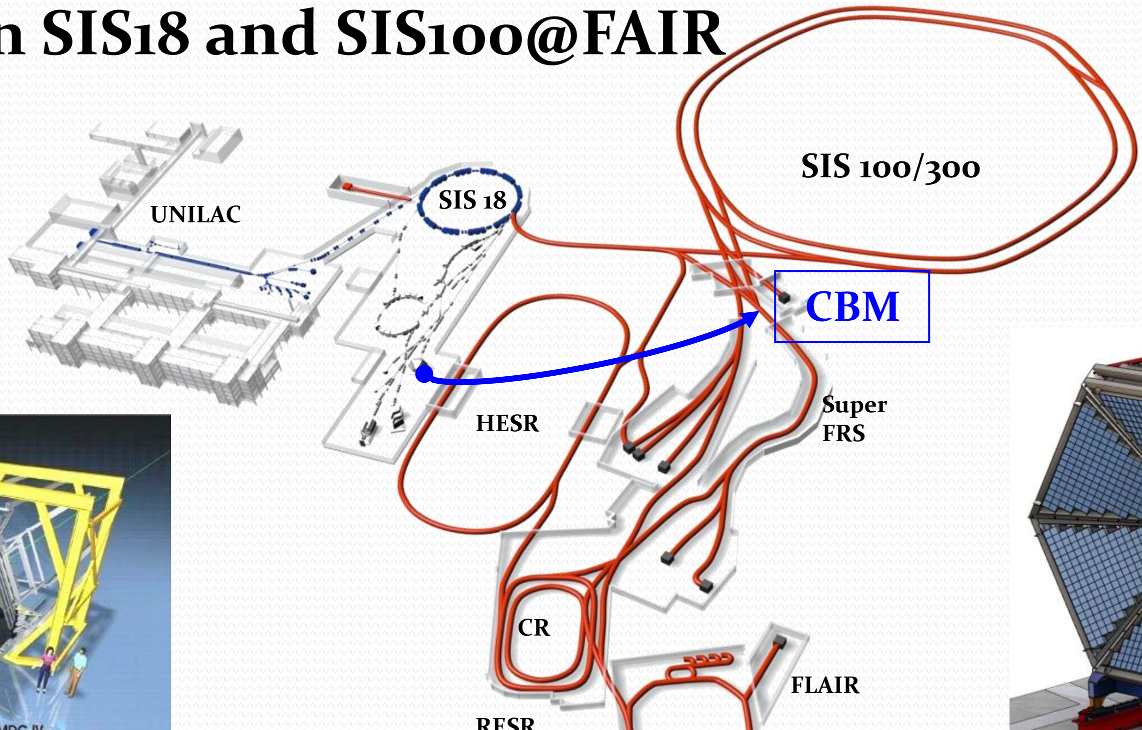
HADES physics program

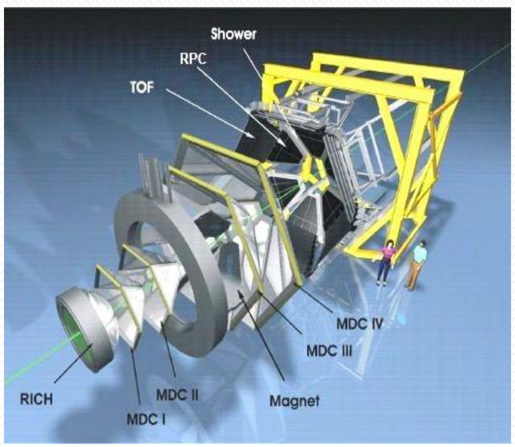
- **H**igh **A**cceptance **D**i**E**lectron **S**pectrometer
- use(d) protons up to 3.5 GeV, pions up to 1.7 GeV and heavy nucleai up to 2 AGeV from SIS18/Bevalac
- studies of in-medium modifications by measuring dielectrons
- hyperon production Σ(1385) and Λ(1405)
- strangeness measurements ϕ, $K^{+/-}$, Ξ(1321) in heavy ion reactions





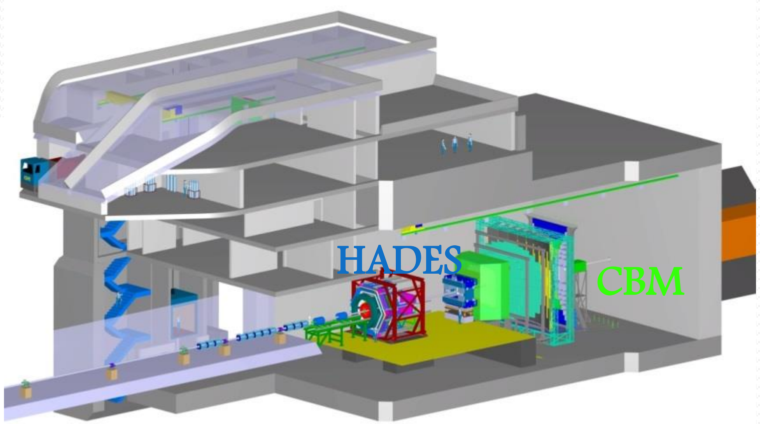
HADES on SIS18 and SIS100@FAIR

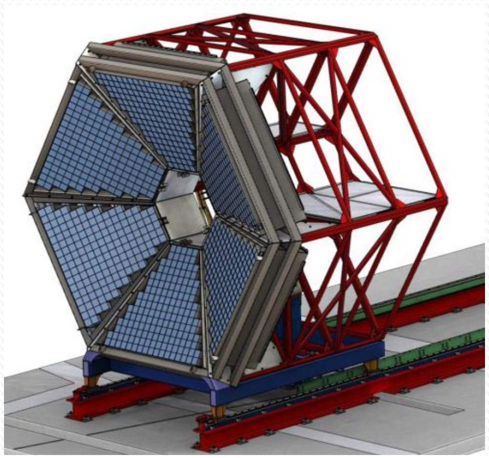




HADES setup

- installed at GSI SIS 18
- six identical sectors
- almost full azimuthal angle
- polar angle 18° - 85°
- high rate counting





ECAL detector

- planned for SIS 100@FAIR
- 978 modules of lead glass + photomultiplier
- polar angle 12° - 45°
- novel electronic for read out

ECAL physics background

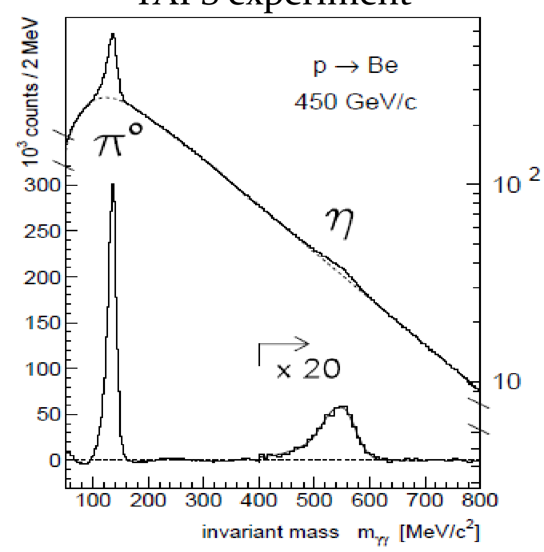
- measurements of the respective π^0 and η meson two gamma decay yields together with the dielectron data for the knowledge of dielectron cocktail and normalization at incident heavy ion energies 2-10 AGeV

- better electron/pion suppression for large momenta (p>400 MeV/c) as compared to the present situation (at lower momenta the electron/hadron identification will be provided by the RICH and RPC)

- combining the two photon detection in the ECAL calorimeter with a charge particle detection in HADES to investigate ω production via the $\pi^0\pi^+\pi^-$ and the $\pi^0 e^+ e^-$ decays (the latter being of importance for the still unsettled question of the ω electromagnetic transition form factor)

- photon measurements are of large interest for the HADES strangeness program which addresses spectroscopy of neutral Λ(1405) and Σ(1385) resonances in elementary and HI reactions

TAPS experiment



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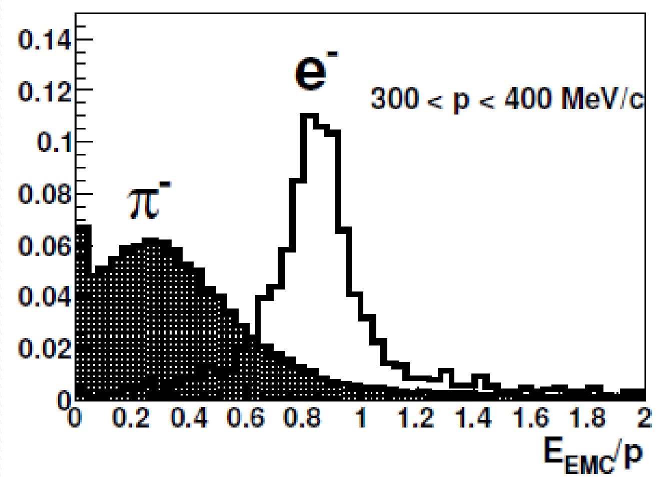
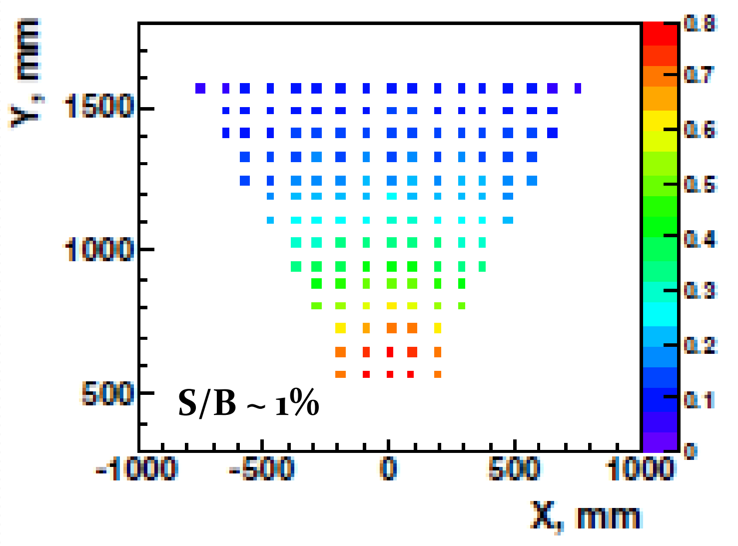
ECAL simulation in GEANT3
π^- e^- separation at Ni+Ni @ 8 GeV



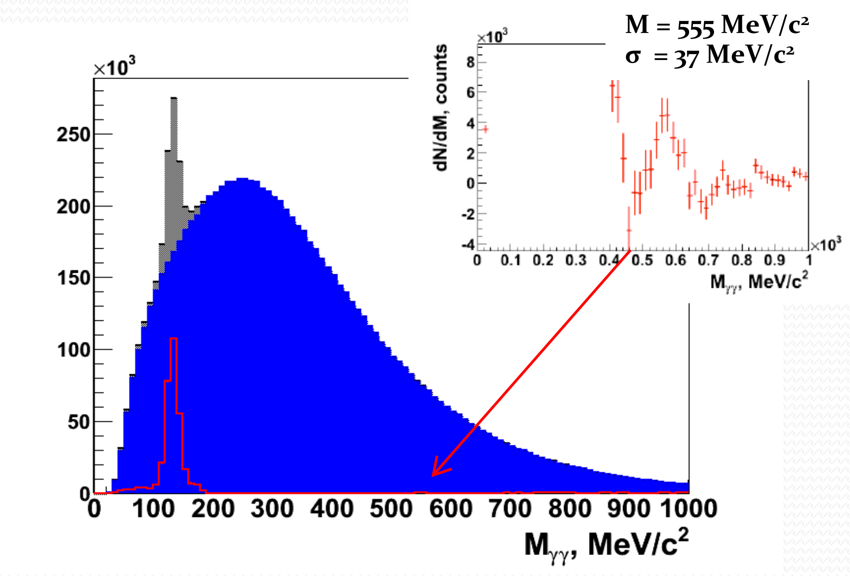
Simulation of the ECAL setup

- implemented in HGeant code (GEANT3 based framework of HADES collaboration)
- simulation of lead glass response split to:
  - shower development in a module
  - transport of the Cherenkov photons
- look-up table approach used for Cherenkov photon to fasten the calculation

Module occupancy in Ni+Ni @ 8 GeV

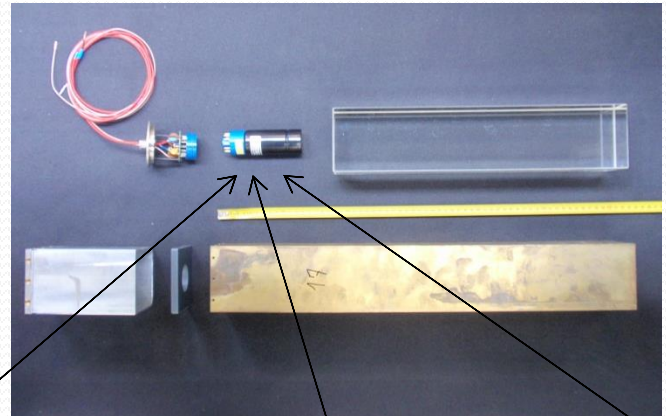


Diphoton invariant mass spectra in Ni+Ni @ 8 GeV



Calorimeter module

- totally needed **978 pieces**
- lead glass on loan from end cap calorimeter of OPAL experiment
- lead glass type: **CEREN 25**
- dimensions 92x92x420 mm
- wrapped in TYVEK paper
- brass can 0.45 mm thick
- optical fiber



Glass properties:

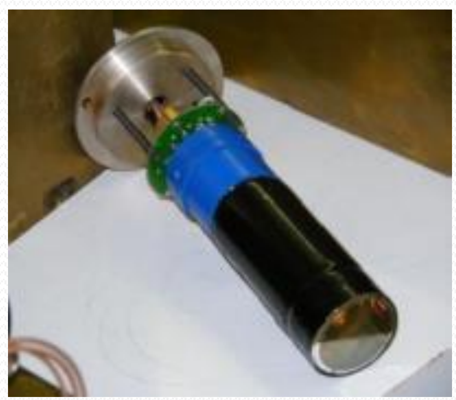
- chemical composition:

SiO_2 -39%,PbO – 55%, K_2O - 2%, Na_2O – 3%)

- density: 4.06 g/cm^3
- radiation length (X_o): 2.51 cm
- refractive index: 1.708 (at 400 nm)
- Moliére radius: 3.6 cm

~~1 inch Hamamatsu R8619~~

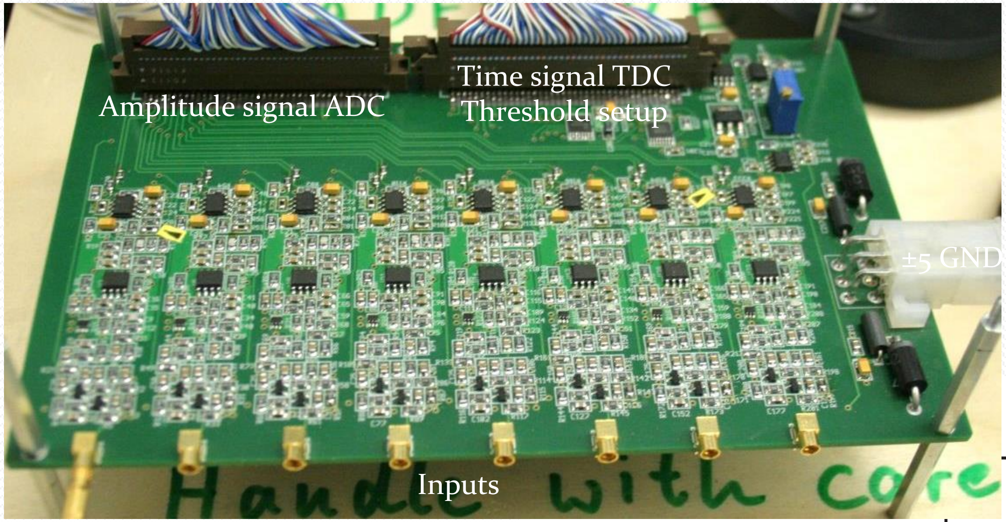
1.5 inch EMI 9903KB



650 pieces from MIRAC experiment (WA98 hadron calorimeter)

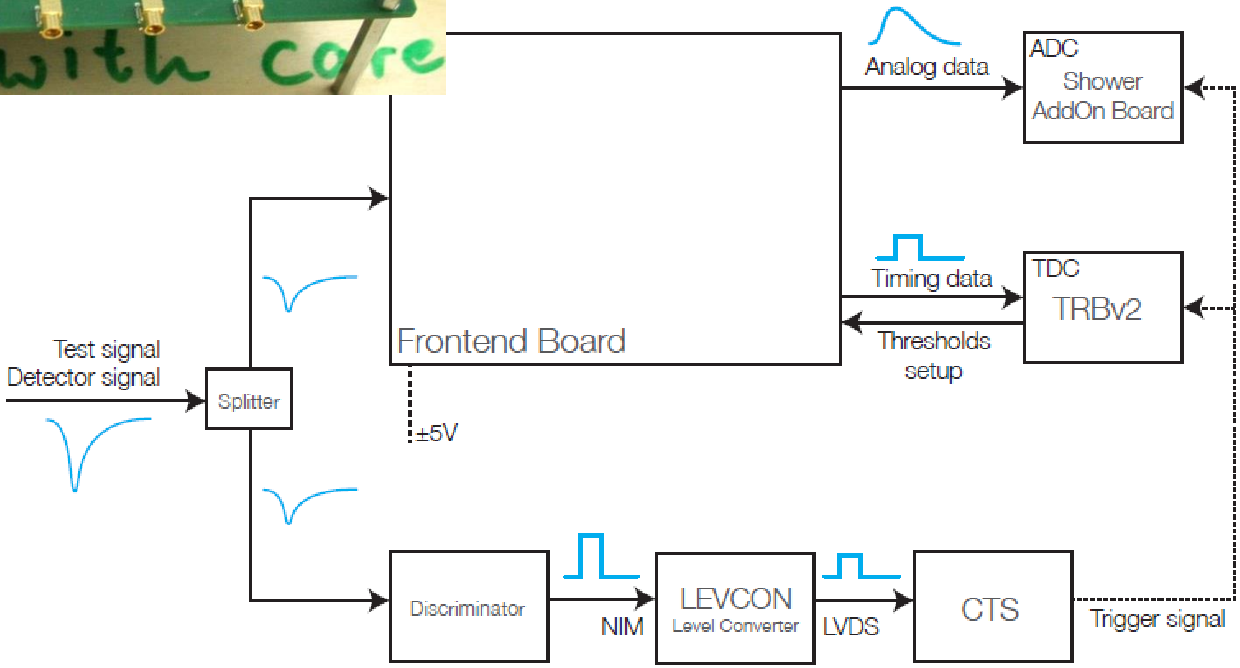
3 inch Hamamatsu R6091

Front-end electronics – Cracow design



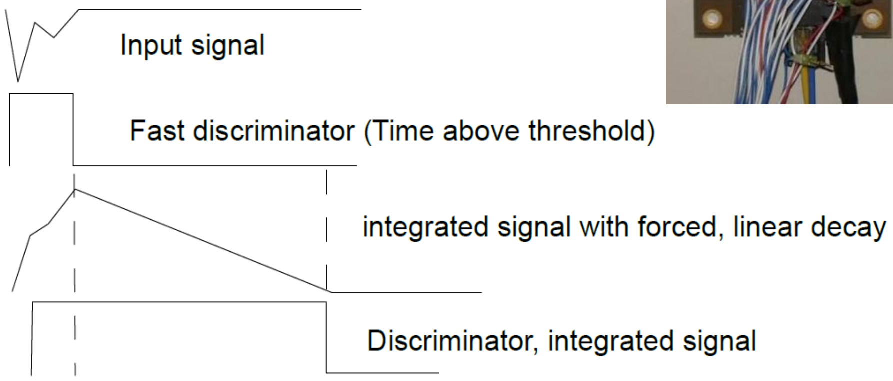
- 8 input channels
- Signal split into two paths:
  - Fast path: fast discriminator for time measurement
  - Slow path: signal integrated for amplitude measurement
- Differential LVDS output
- Discriminator threshold for each channel via slow control lines
- ADC and TDC done by TRBv2 boards

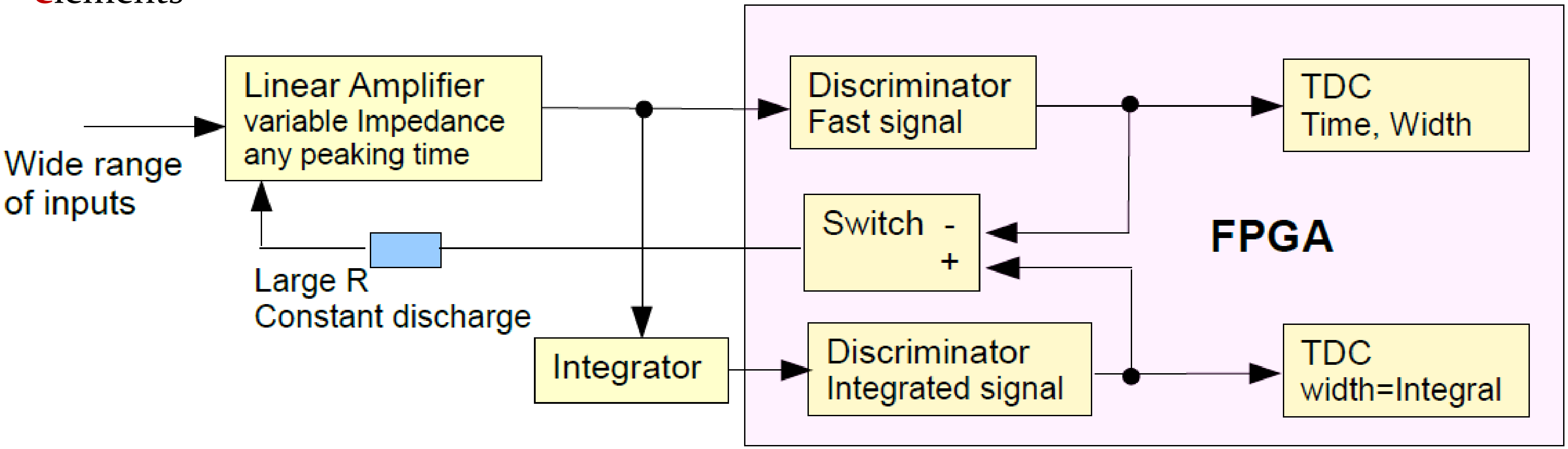
- Different shaping time and gain tested
- Energy resolution with **pulser: 0.6%** at 100 ps time precision
- Energy resolution with **LED-PMT signal: 3.6%** at 150 ps time precision



Charge measurement with FPGA – GSI front-end board

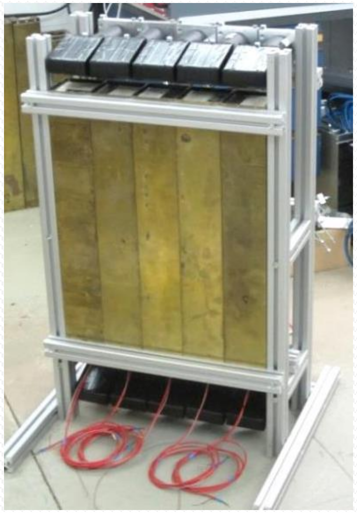
- **Idea:** Modified Wilkinson ADC
- Integrate input signal with a capacitor
- Discharge via current source -> fast crossing of zero
- Q2W: Measure time to reach zero ~Q using an FPGA-TDC
- COME & KISS design: **k**eep **i**t **s**mall and **s**imple by using **c**omplex **com**mercial **e**lements





Previous tests of calorimeter concept

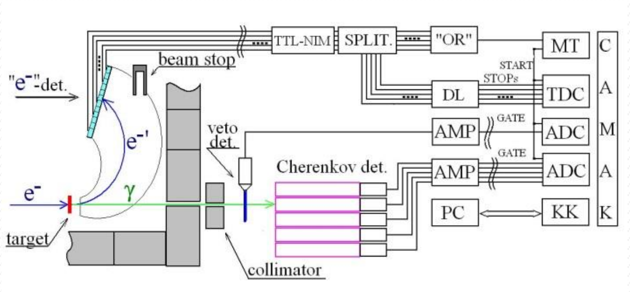
Cosmic muons



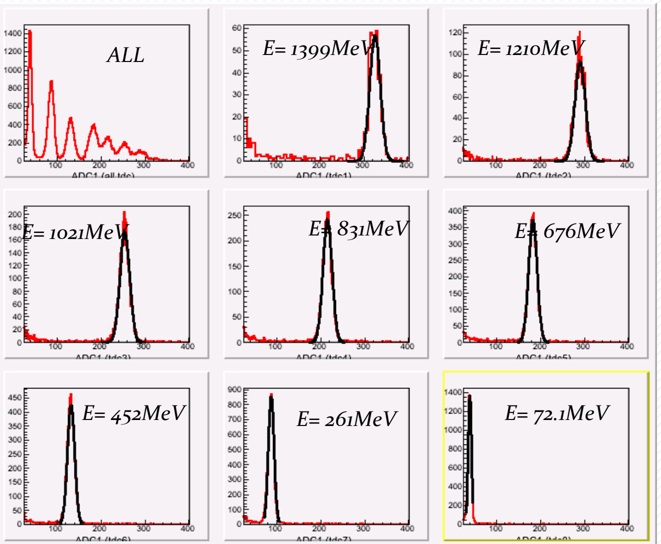
- energy ~ 2 GeV
- energy deposit in module ~ 200 MeV
- Cherenkov light output corresponds to ~ 1200 MeV electrons
- count rate ~20 particles / hour

Gamma beam (MAMI Mainz)

secondary γ beam of energies in range from *0* to energy of the electron beam

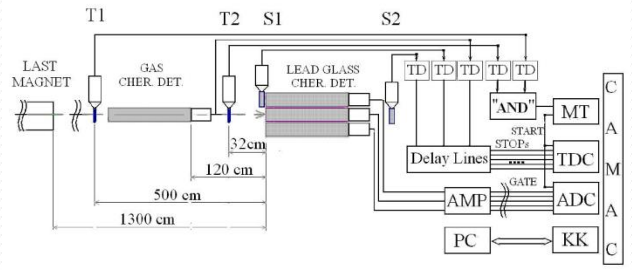


E_e=1508 MeV, γ energy spread <= 1%



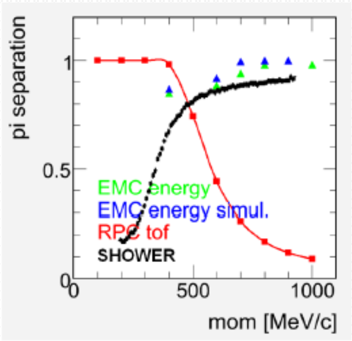
Pion/electron beam (CERN)

secondary π- beam of 0.4 – 6 GeV/c with admixture of e-



- time resolution of 215 ps for 800 MeV e-
- energy resolution 6.9% for 1 GeV e-

e^-/π^- separation factor



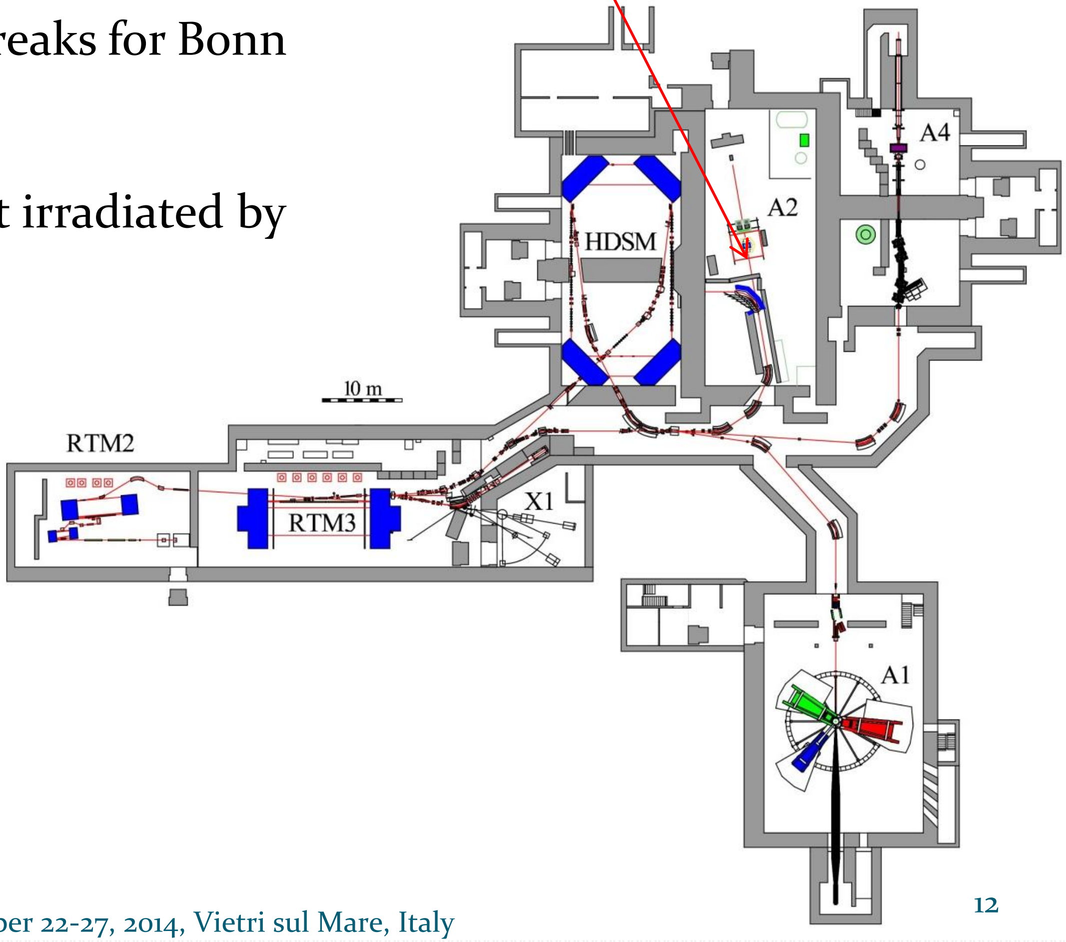
Motivation for new in beam tests

- compare energy resolution of modules equipped with 1“, 1.5“, and 3“ photomultipliers (decide, whether we can (not) use 1 inch PMTs)
- verify functions of developed electronics with real beam signals
- measure energy leakage between neighbor modules and its effect on energy resolution
- measure response of modules on declined beam (energy distribution between the modules and losses)
- provide more data to calibrate single detector response in simulations (tune photon transport in the modules)

To fulfill these tasks secondary **gamma beam at MAMI Mainz** facility was used…

MAMI Mainz – test conditions

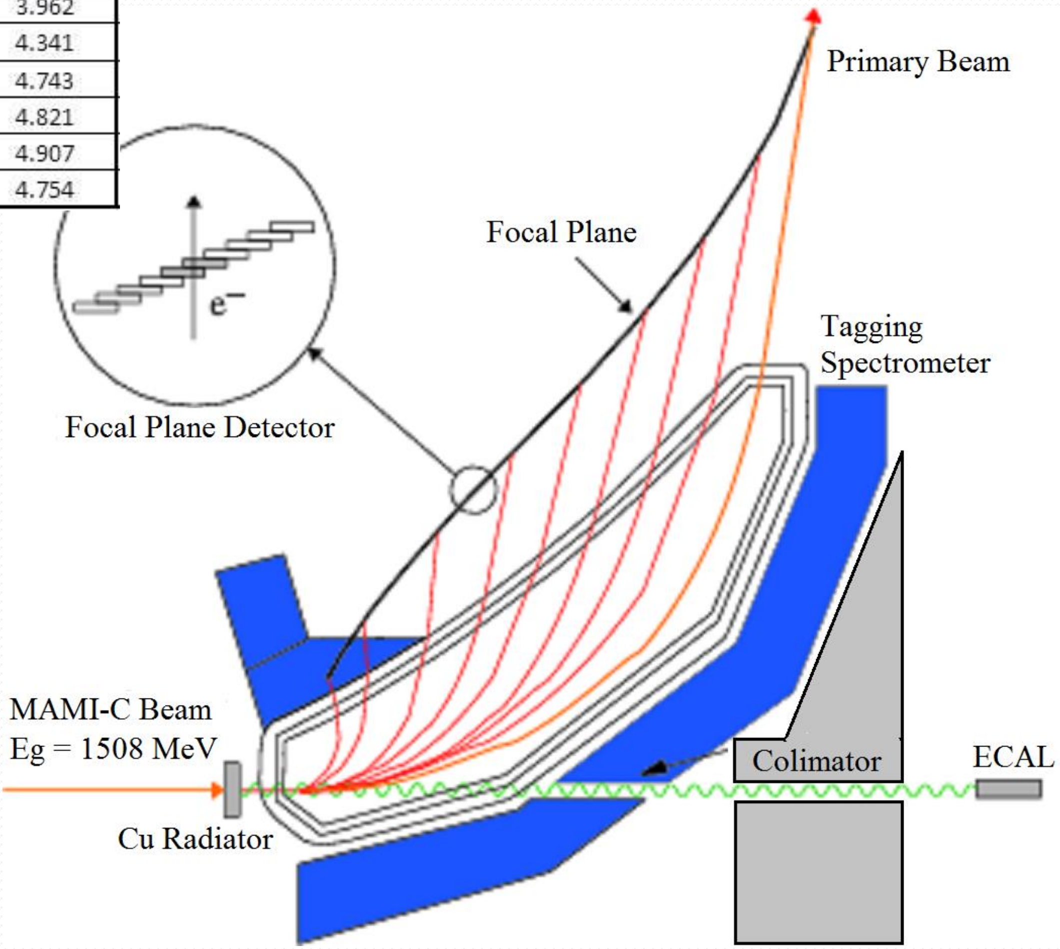
- used secondary beam of gamma photons from MAMI facility at Johannes Gutenberg-Universität Mainz
- 7. 1. 17:00 – 9. 1. 2014 5:00 with breaks for Bonn group
- γ photons produced on Cu-target irradiated by 1508.4 MeV electron beam
- γ beam intensity ~ 5 kHz (100 Hz in trigger)



Tagger

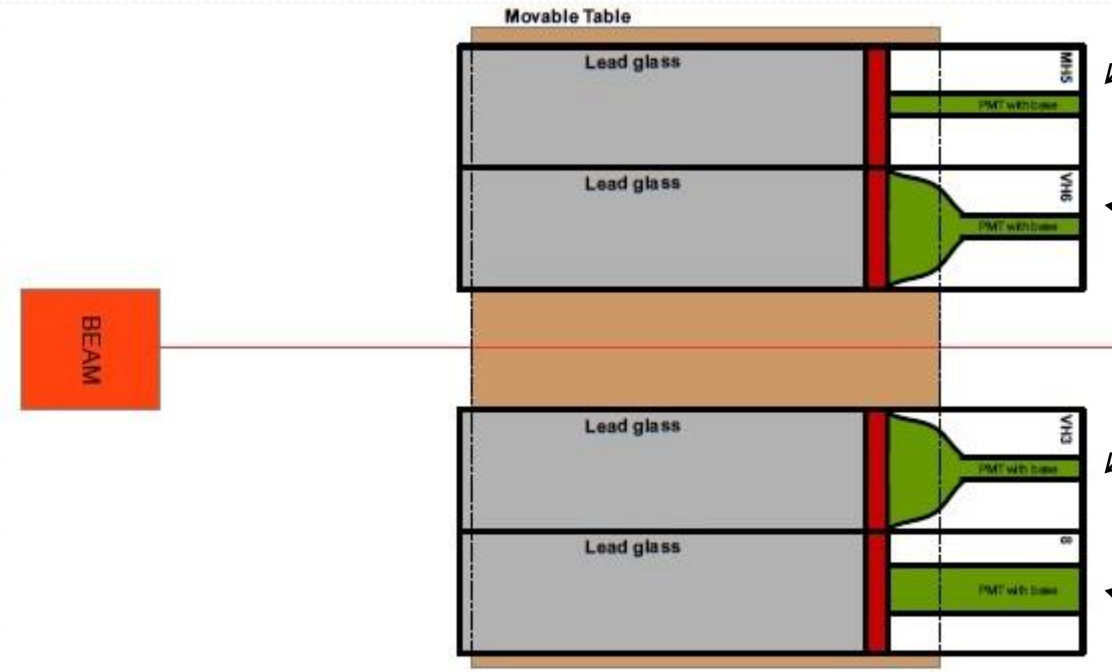
Tagger channel (from1)	E_g Low	E_g High	E_g Mean	E_g Bite
2	1398.322	1400.327	**1399.325**	2.005
66	1216.127	1219.411	**1217.769**	3.284
121	1030.452	1034.414	**1032.433**	3.962
170	841.208	845.549	**843.379**	4.341
210	675.710	680.453	**678.081**	4.743
261	458.898	463.720	**461.309**	4.821
306	268.440	273.348	**270.894**	4.907
352	78.992	83.746	**81.369**	4.754

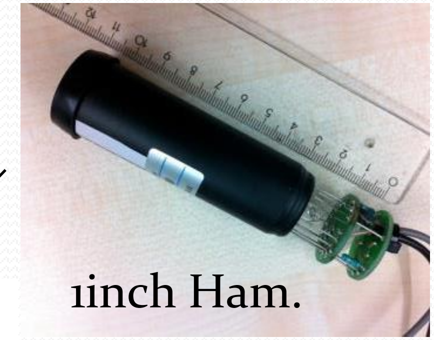
- used tagger to select 8 known gamma energies
- 8 different trigger signals – 8 energies measured in one measurement
- beam collimated by Ø 2 mm lead collimator placed 1.5 meters upstream
- beam size in front of the modules ~ 6 mm

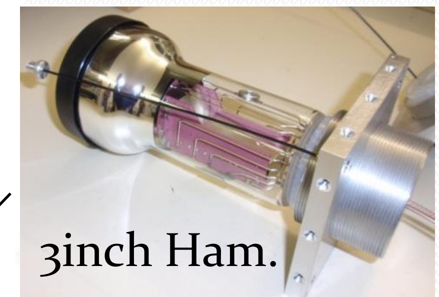


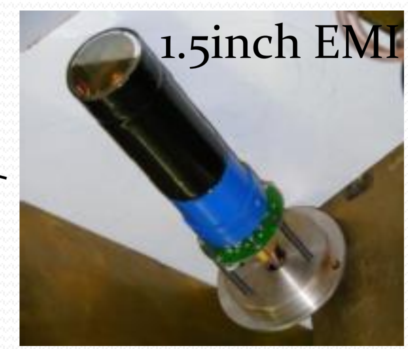
Experiment layout

- 4 modules placed on movable table (remote control, 1 cm step)
- middle position empty for beam to Bonn group experiment









Experiment read-out systems

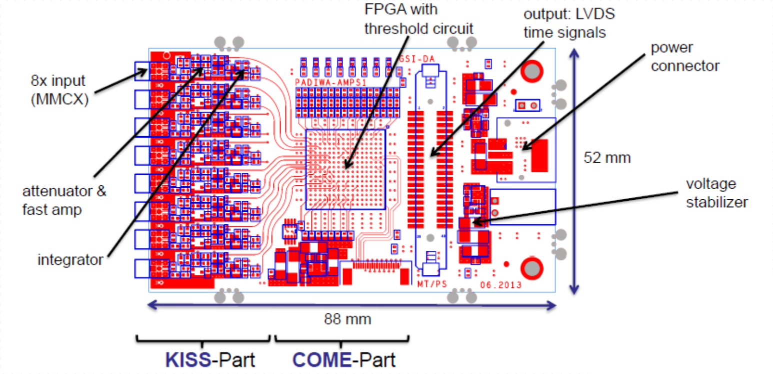
Data taken by four different readout systems:

CAEN adc – reference DAQ system

Rhode&Schwarz oscilloscope

“Cracow” front-end board + TRB2

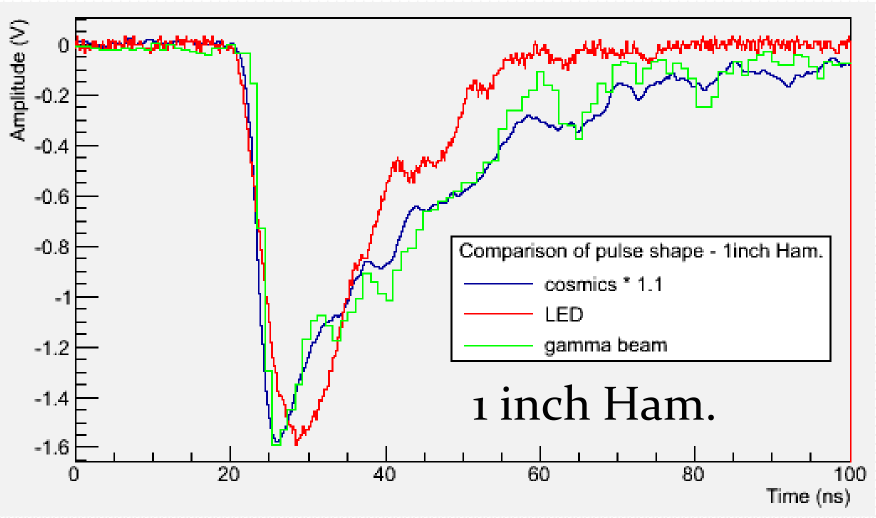
PaDiWa Amps + TRB3

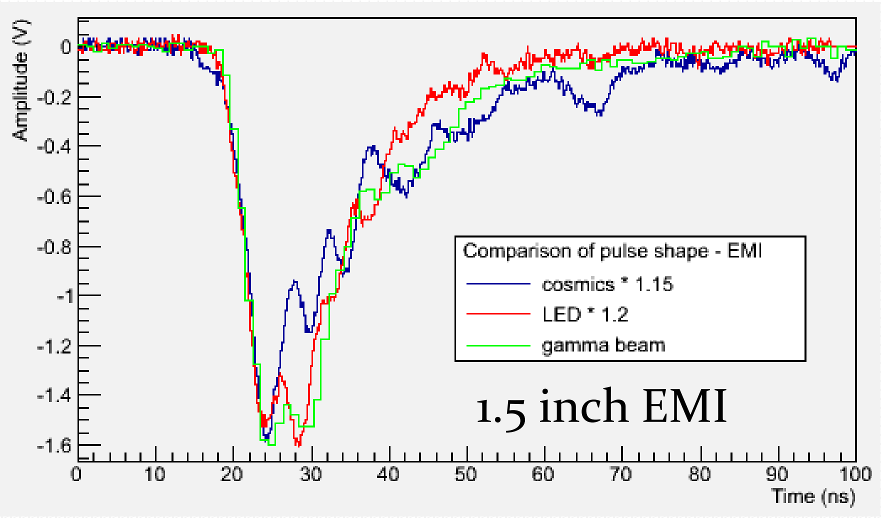


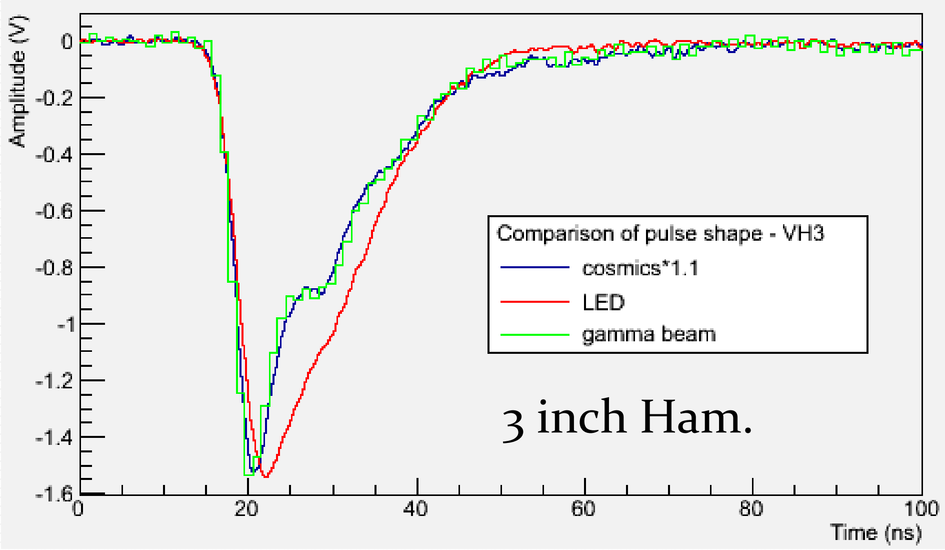
Measurements with CAEN ADC

- CAEN DT5742
- 16 channels ADC – stores 1024 values in 1 μs window
- common trigger (8 tagger signals were split, sum of it was put to common trigger, different trigger channels were put to last 8 adc channels of CAEN)
- measurements with and without shaper – waveforms of raw signal from module as well as shaped signals stored

Comparison of pulse shapes



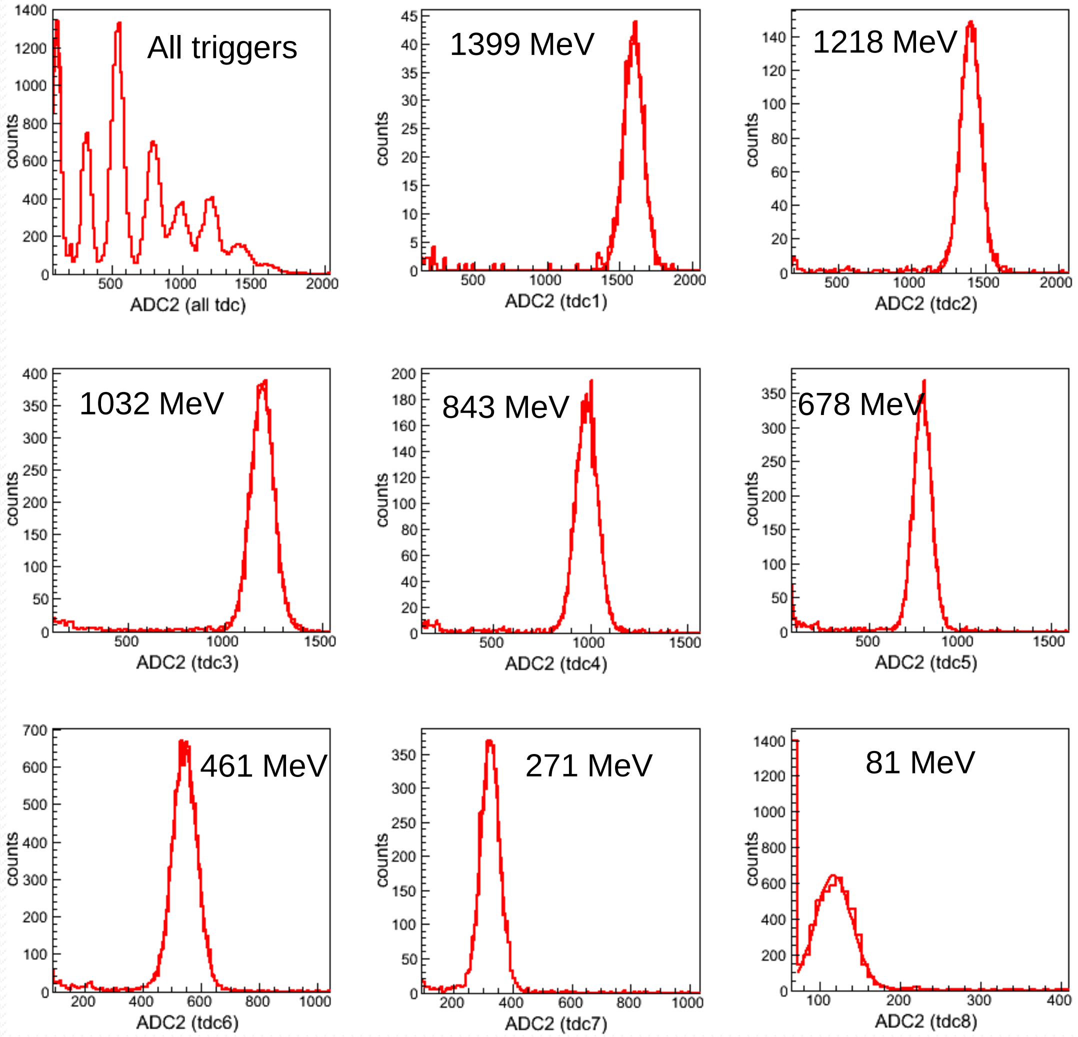




green curve induced by γ photon of 1399 MeV

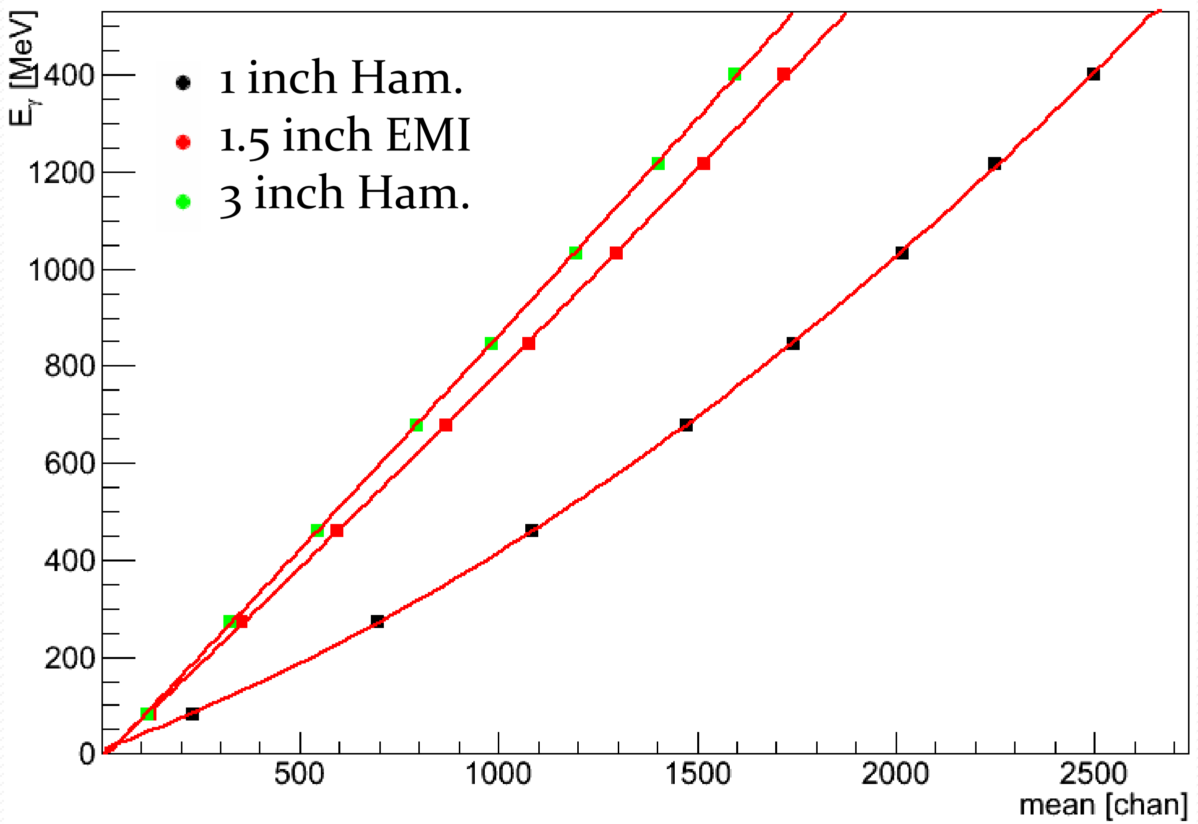
ADC plots

- E_e = 1508.4 MeV
- γ energy spread ≤ 1%
- 3inch Hamamatsu module at nominal HV (VH3)
- measured with CAEN ADC
- signal shaped by MA8000 shaper – channel 3
- energy 81 MeV downscaled 4x
- energy 271 MeV downscaled 2x



Energy calibration

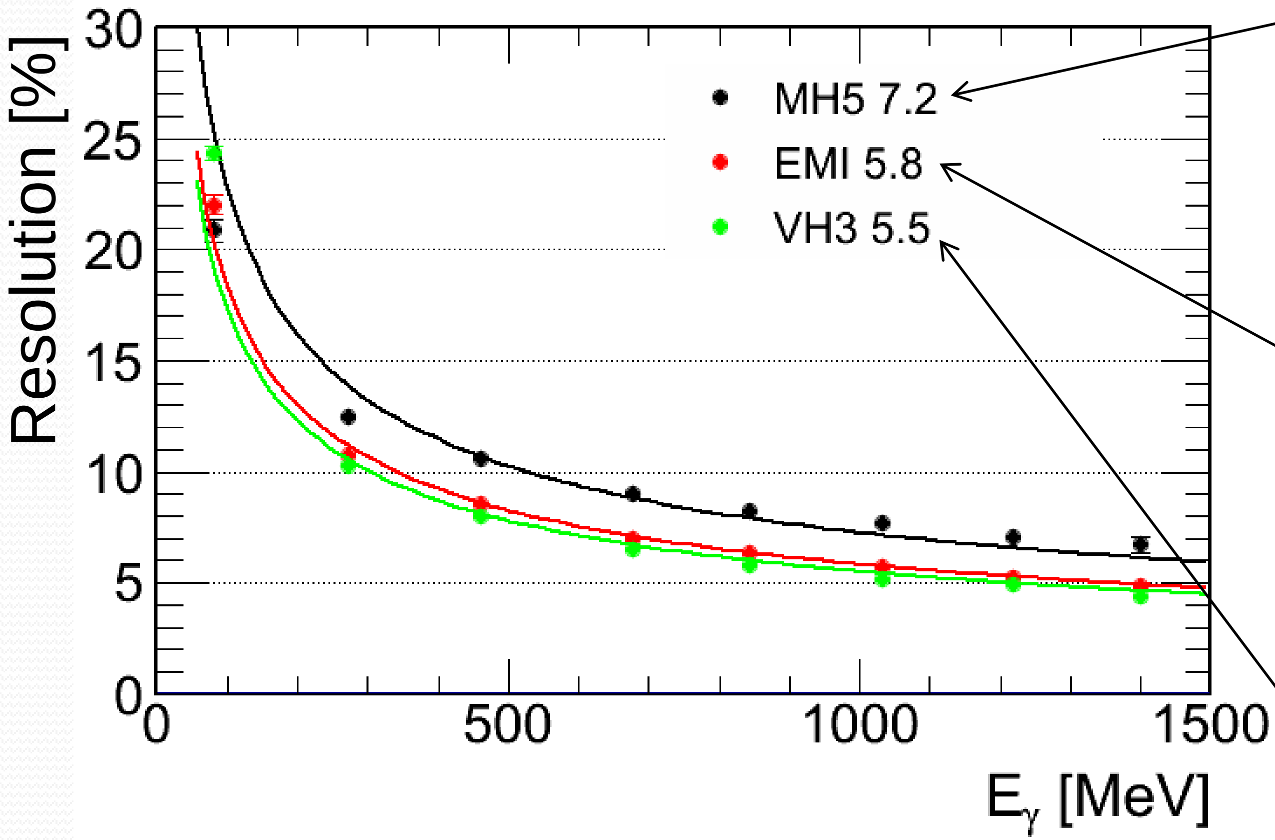
- measured with CAEN ADC
- signal shaped by MA8000 shaper channel 3 (linear one)

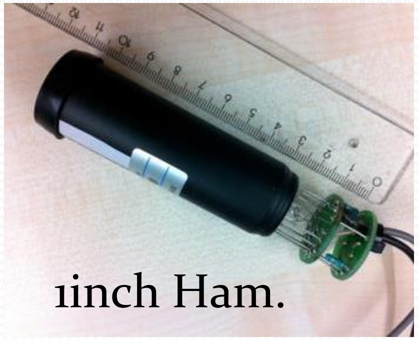


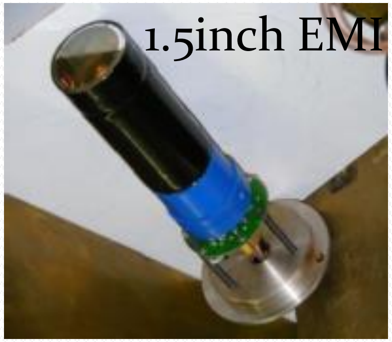
all detectors at nominal voltage (1“ Hamamatsu close to maximal – saturation effects)

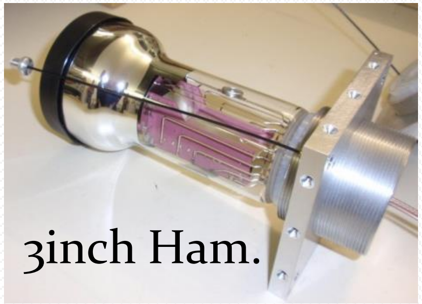
Relative energy resolution

Energy resolution behind the names of modules is for 1 GeV photon…



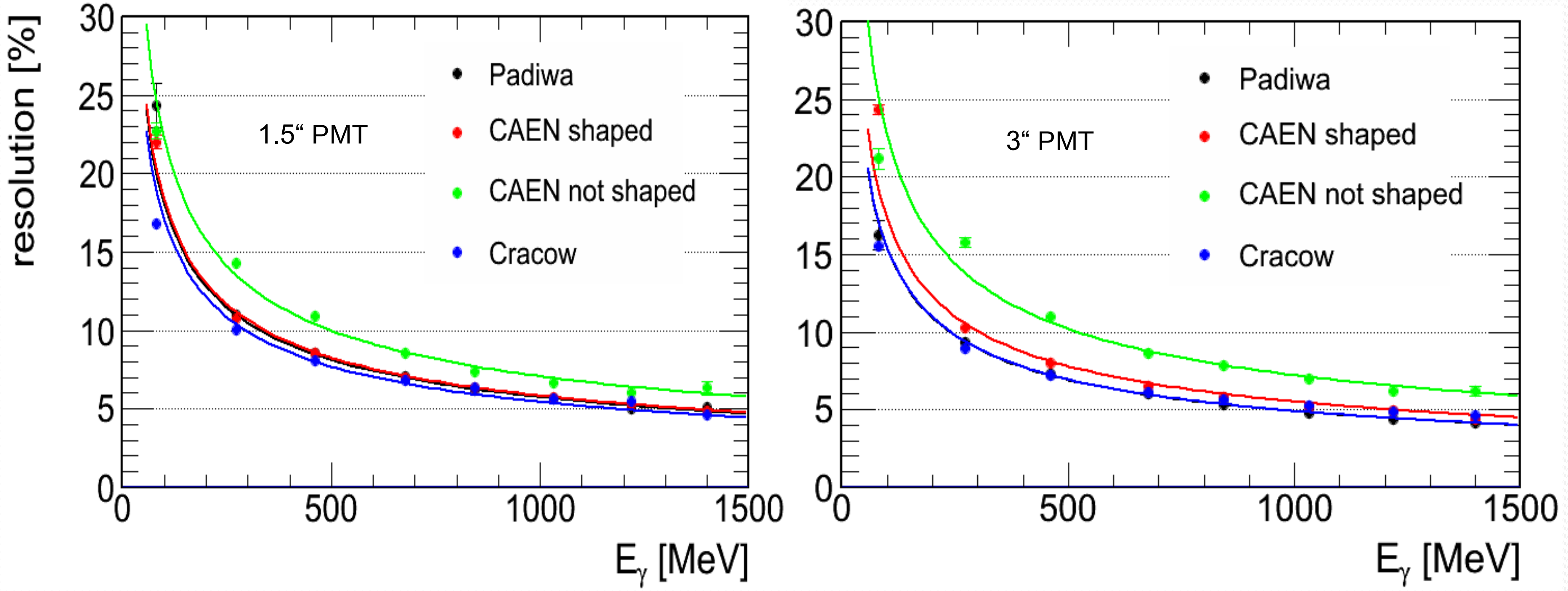






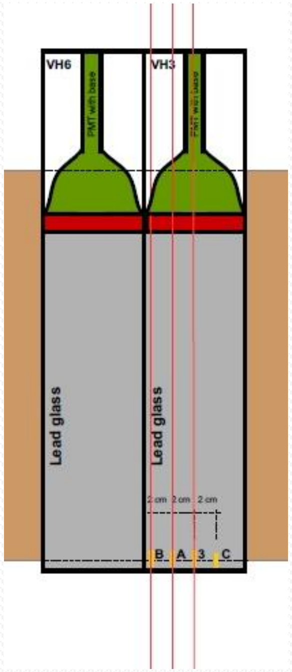
measured with CAEN ADC, signal shaped by MA8000 shaper

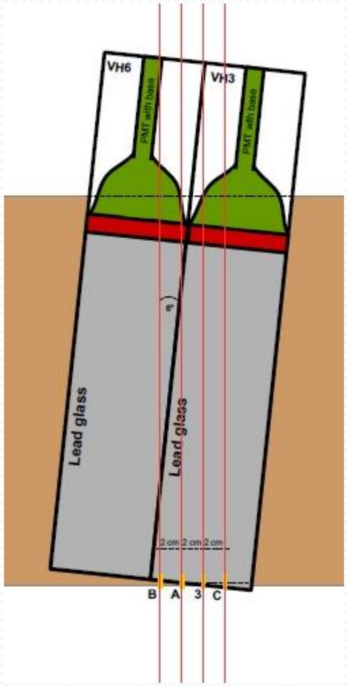
Relative energy resolution measured with different read-out systems

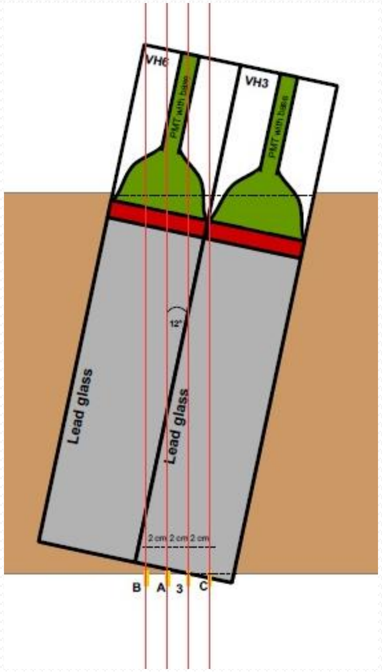


Measurement with rotated modules – experiment layout

- measured modules with 3 inch Hamamatsu photomultipliers (VH3 and VH6)
- no rotation and two declination angles (6° and 12°)
- read output from both modules by CAEN adc, signal shaped by MA8000 shaper







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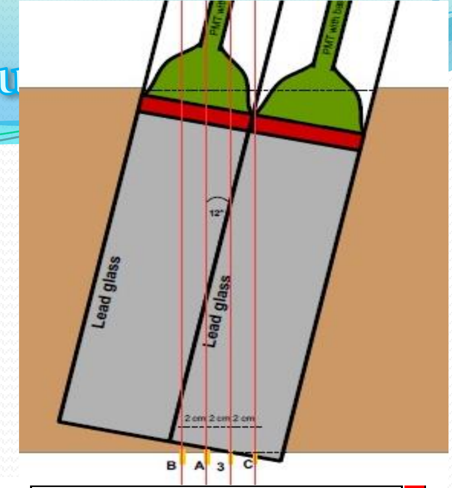
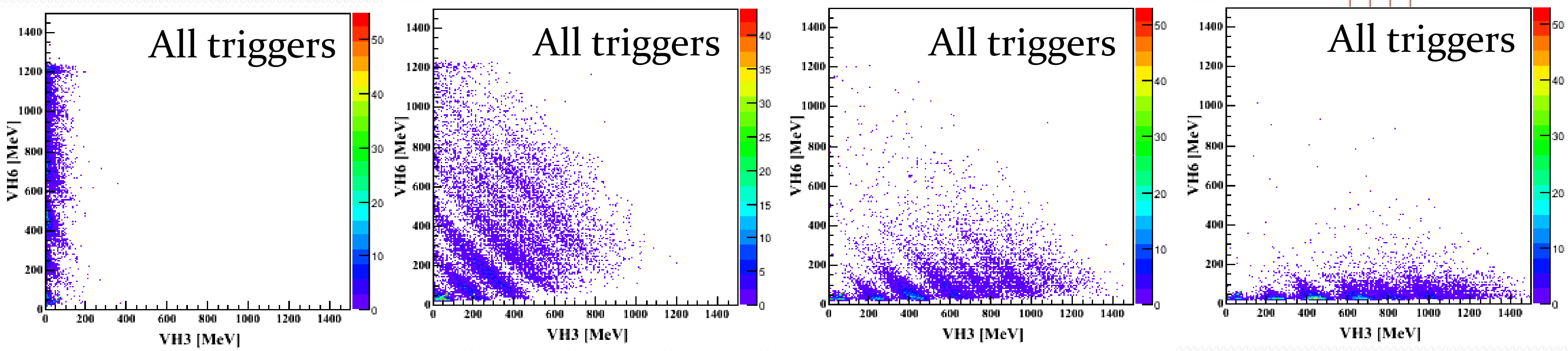
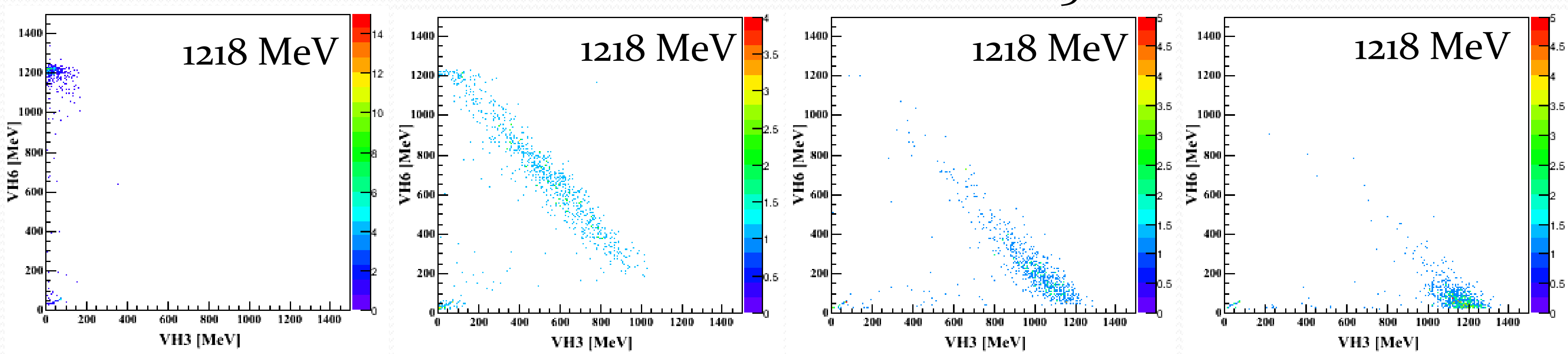


Energy distribution between the modules – VH3 versus VH6

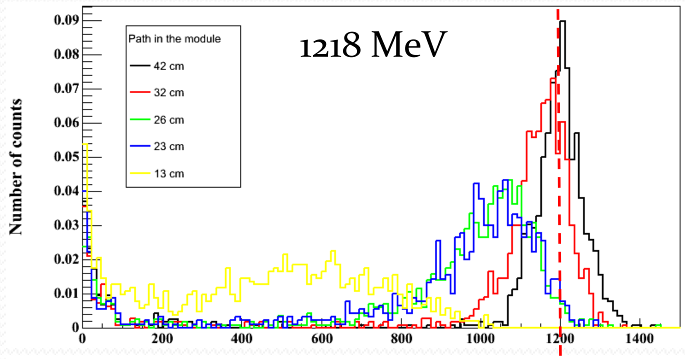
12° rotation angle, 3 inch Hamamatsu modules at nominal HV

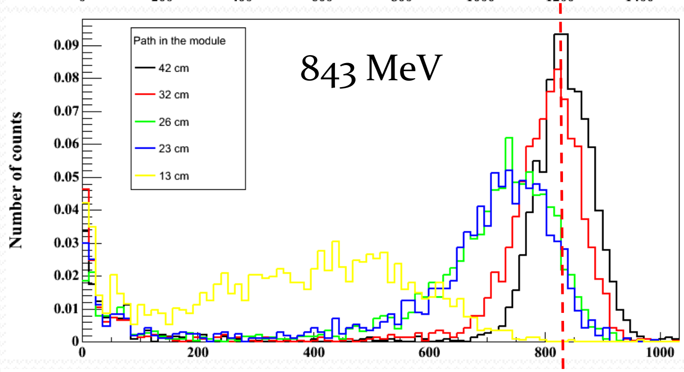


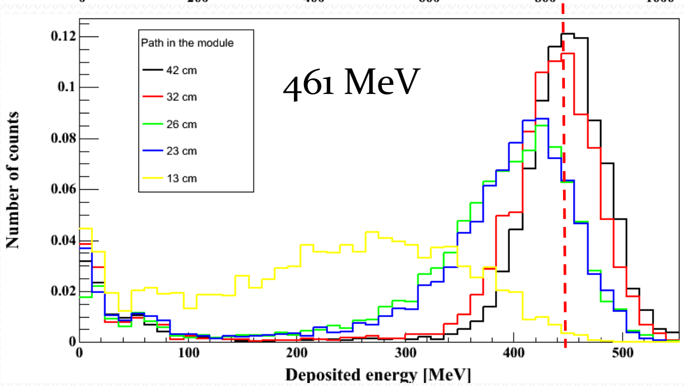
Position B Position A Position 3 Position C

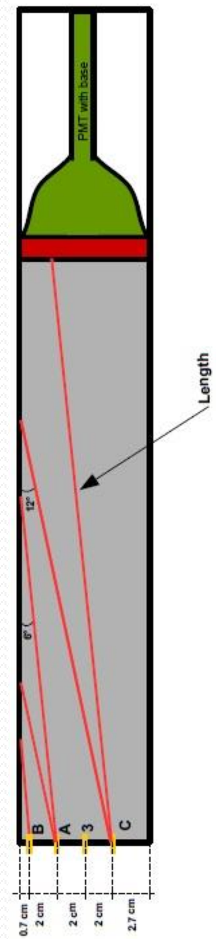


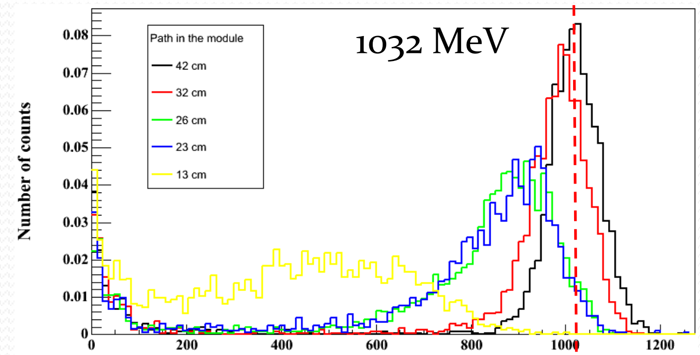
Deposited energy in VH3 for different path length of the γ photon

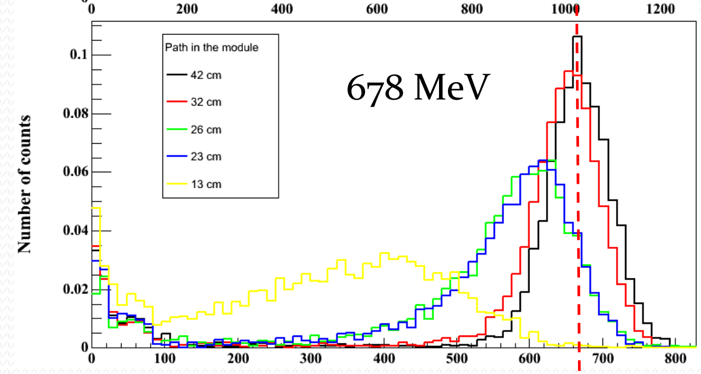


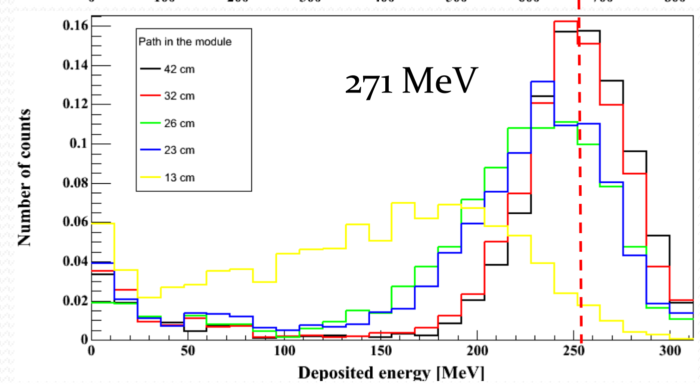




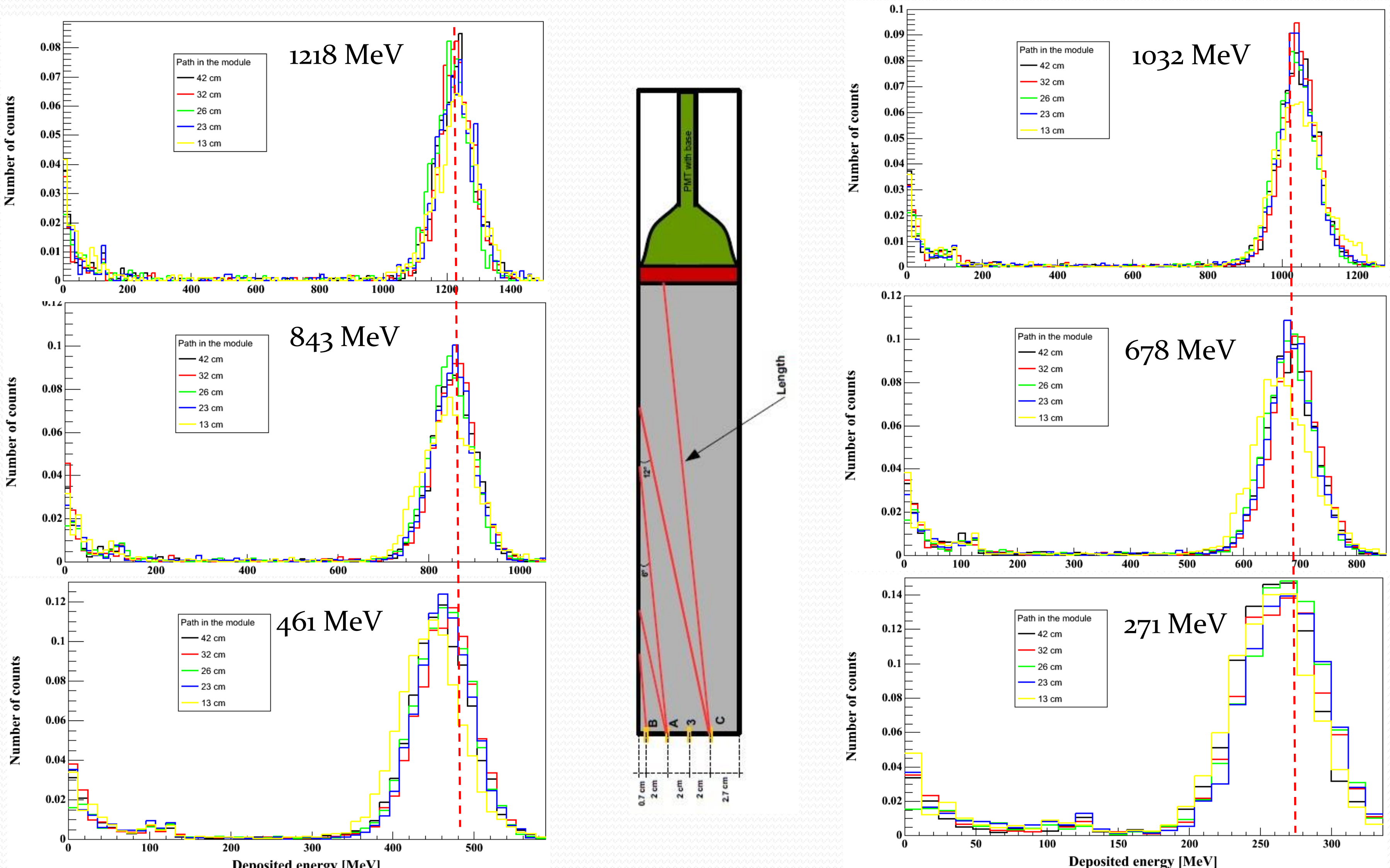




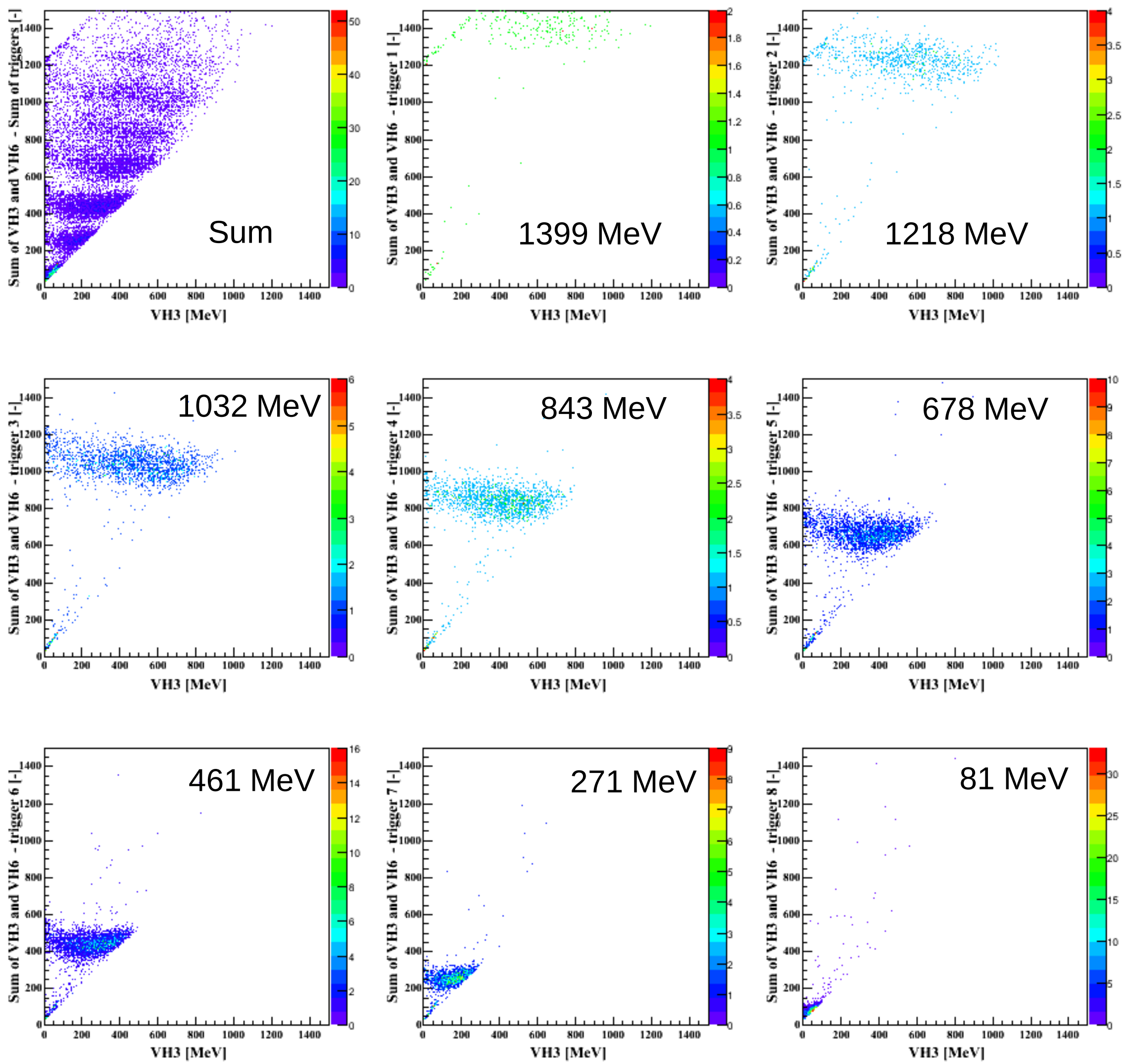


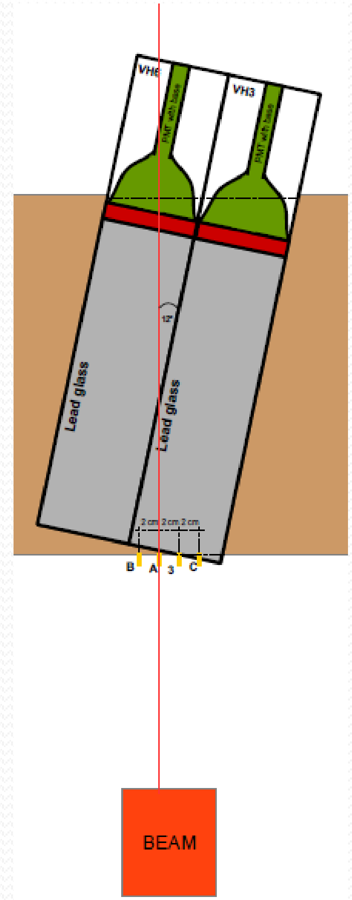


Sum of energy for different path length of the γ photon



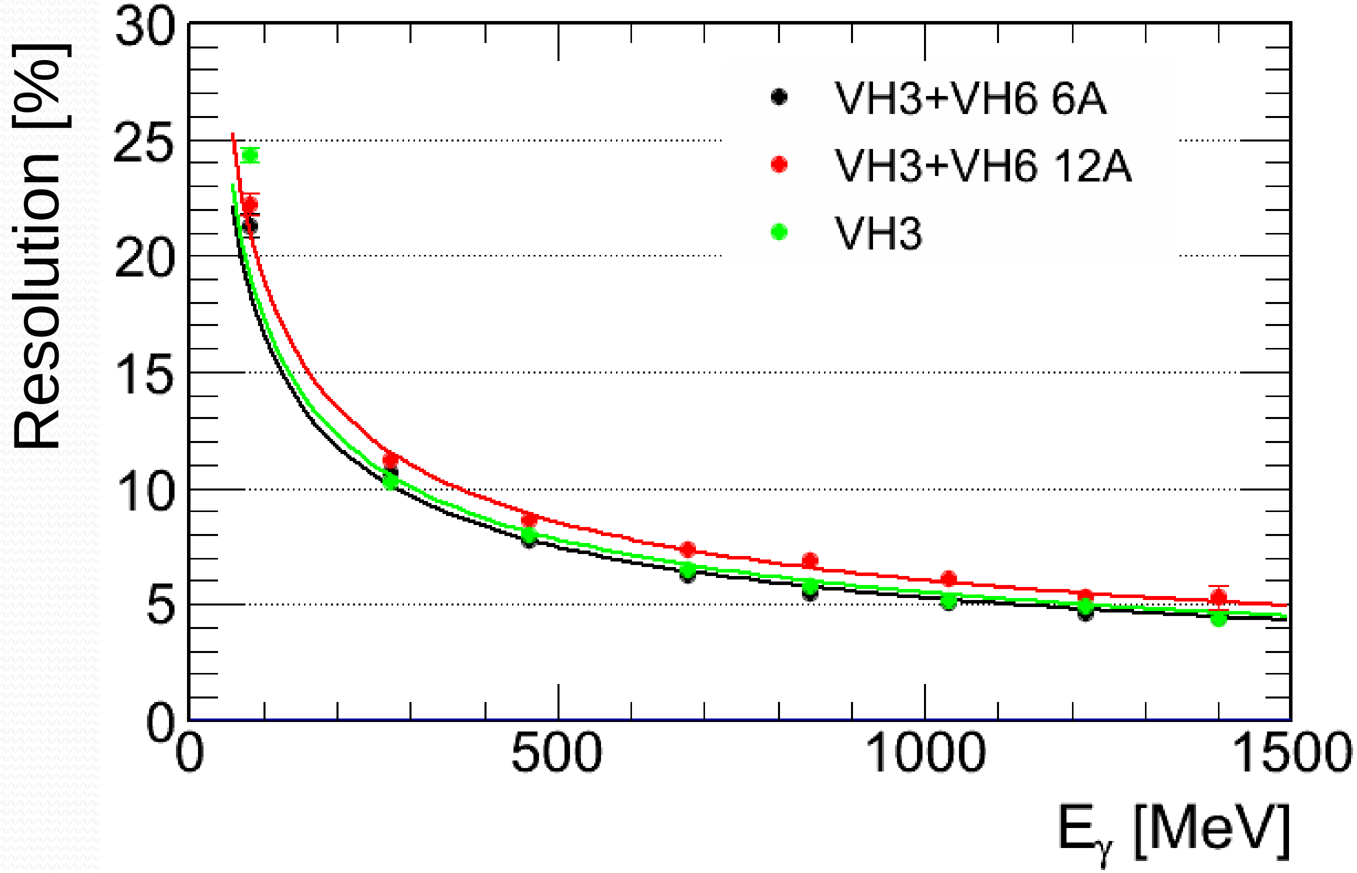
Sum of energy versus energy deposited in VH3





beam rotated by 12° with respect to module axis – position A

Relative energy resolution for different path length in the module VH3



at 1 GeV:
central: 5.5%
6-A: 5.1%
12-A: 6.1%

Path length in VH3 for 6-A is 26 cm, path length in VH3 for 12-A is 13 cm.

Summary

Motivation for calorimeter construction:

- Improved dilepton spectroscopy by HADES – lepton and photon pairs at the same time

Current status:

- ~150 modules assembled, ~70 modules measured in detail with cosmics muons
- Modules equipped with 1.5 and 3 inch photomultipliers successfully tested on γ and pion beams, usage of 1 inch photomultiplier is not suitable
- Energy resolution and response of rotated modules measured in detail
- Mechanical construction designed, simulations performed, software for read-out prepared
- Prototype of LED based monitoring system proven, but further development needed
- Two novel solutions for front-end electronic under development
- TDR updated and submitted to FAIR management, reviewers questions answered

Plans:

- Finish front-end electronic modules and LED monitoring system
- Build the detector

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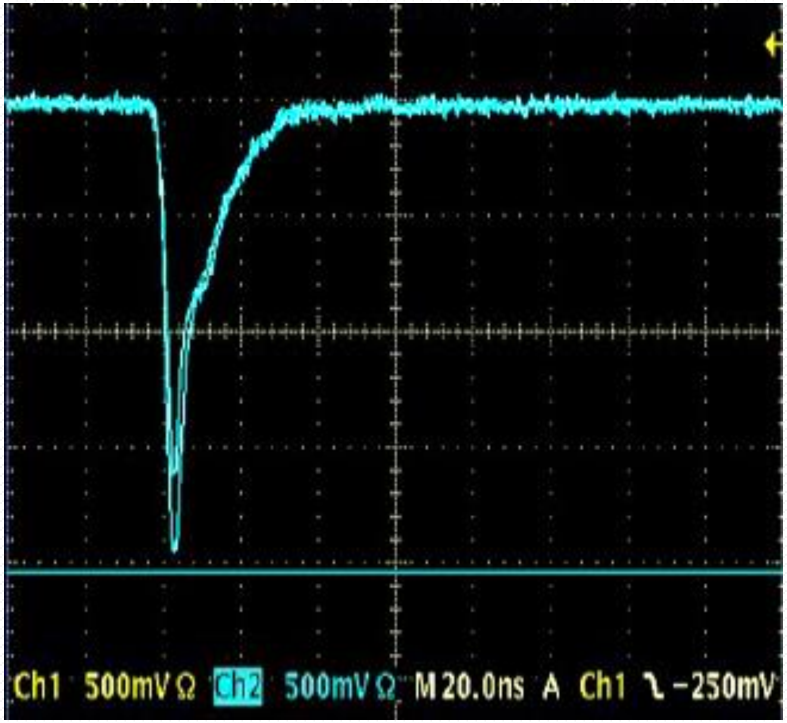
Back-up slides

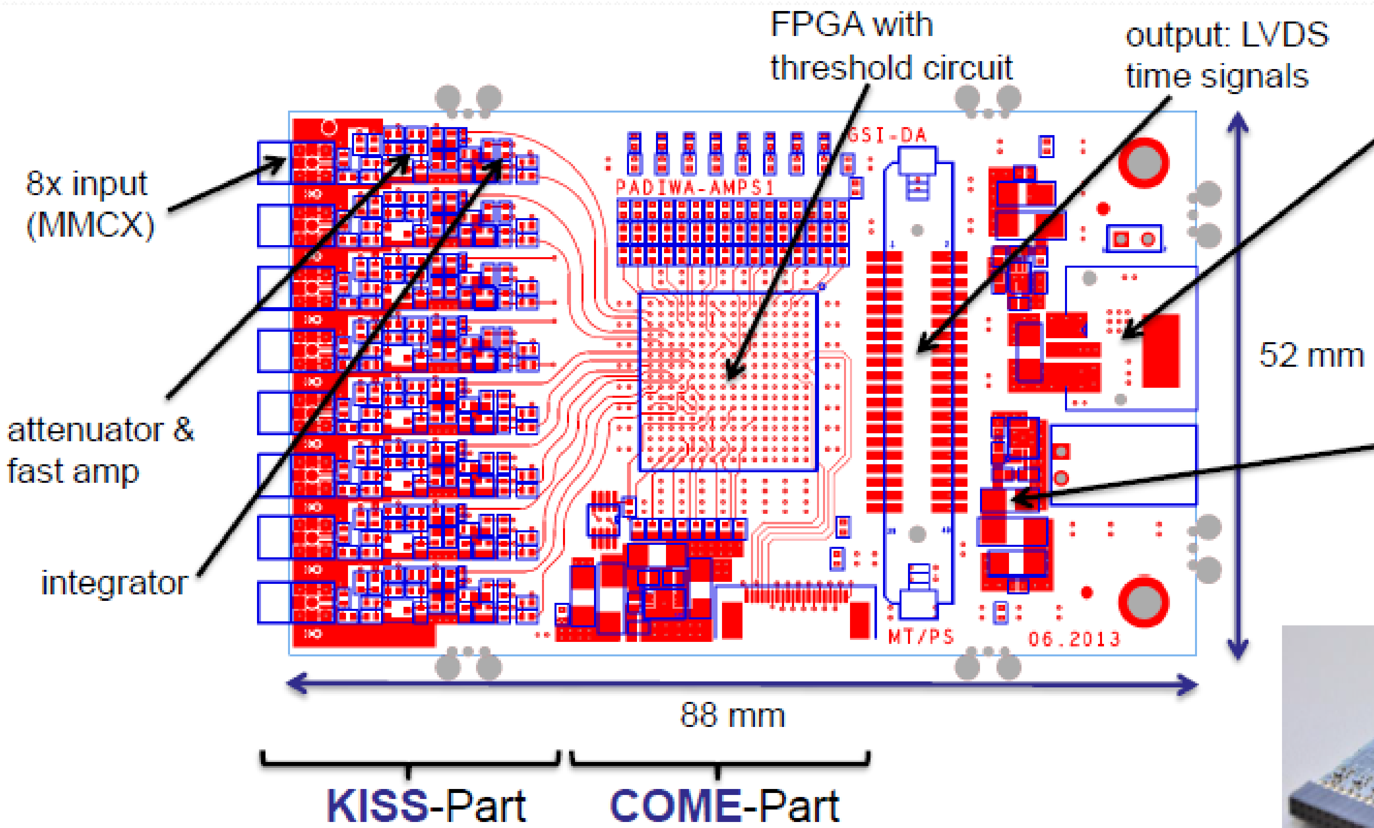
Detector response & requirements on electronics

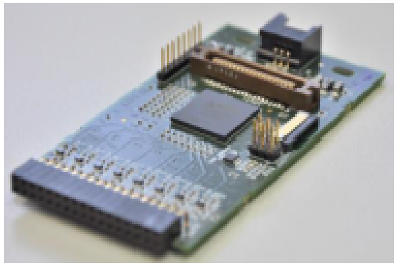


Signal parameters	
Rise time	3 ns
Fall time	50 ns
S/N ratio	> 12.5
Pulse amplitude at 20 MeV	50 mV
Pulse amplitude at 600 MeV	1.5 V
Expected hit rate	10 kHz / channel
Read-out parameters	
Time resolution	< 500 ps
Dynamic range energy	50 mV – 5 V
Energy measurement accuracy	5 mV
Final energy resolution	5%/sqrt(E), E in GeV

according to ECAL TDR

New PADIWA-AMPS1 layout with Q2W (topside)

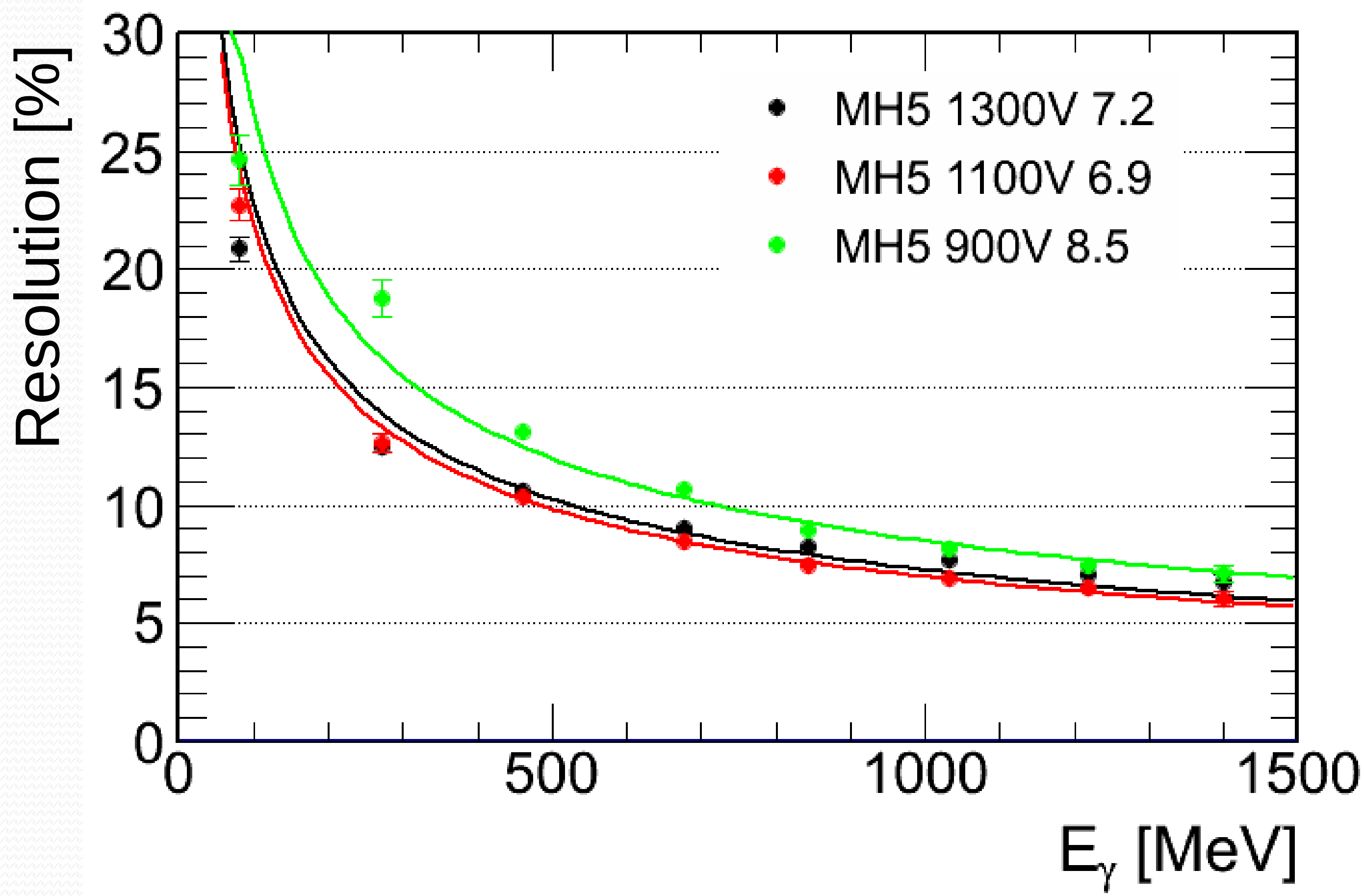




Basis: PaDiWa front-end board for TRBv3

Already several variants tested (different gain, integration time…)

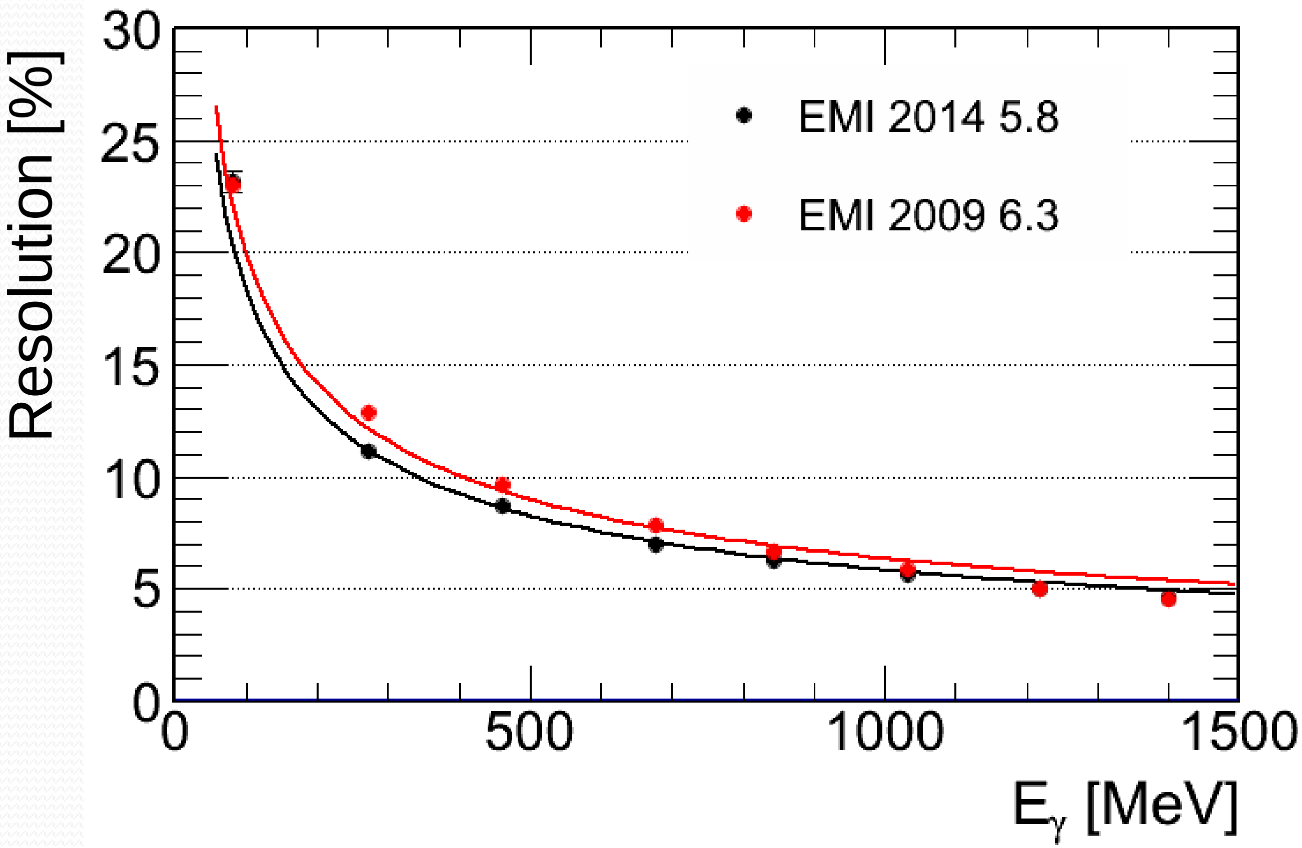
Relative energy resolution – 1 inch Hamamatsu at different HV



Nominal HV for 1 inch Hamamatsu to get the same pulse high as from 1.5 and 3 inch PMTs is -1300V.

Relative energy resolution – comparison with previous experiment at MAMI

Measured with the same module nr. „8“, same HV, but different shaper and ADC.



Energy deposited by parallel beam