Detection of high-energy protons and γ-rays using a novel $LaBr_3(Ce)$-$LaCl_3(Ce)$ phoswich array

E. Nácher, A. Perea, G. Ribeiro, J. Sánchez del Río, O. Tengblad
Instituto de Estructura de la Materia – CSIC, Madrid

M. Mårtensson, A. Heinz, T. Nilsson
Chalmers University, Göteborg

Outlook

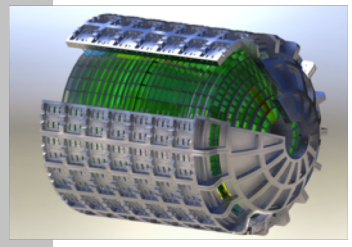
- Introduction: experimental motivation
- Precedents: small cylindrical phoswich and PSA
- CEPA4, a bigger phoswich array
- Summary and conclusions

Experimental motivation: R3B

RIBs@1 AGeV

A universal fixed-target experiment for complete kinematics measurements of reactions with relativistic RIBs (300 – 1500 AMeV). Based on the current LAND setup

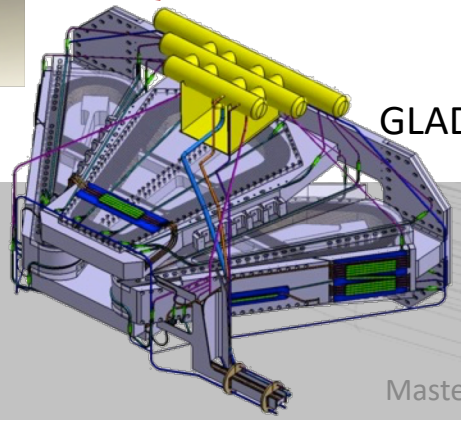
- Target
- Tracker
- Calorimeter



Neutrons

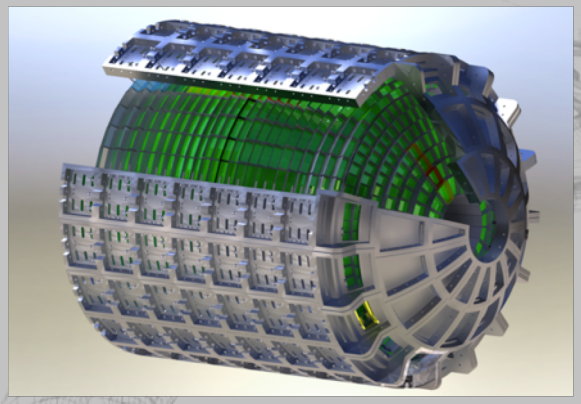
Protons

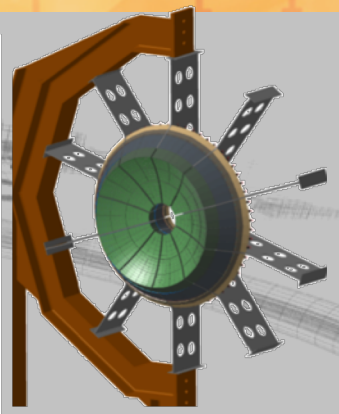
Heavy fragments



GLAD: GSI Large Acceptance Dipole

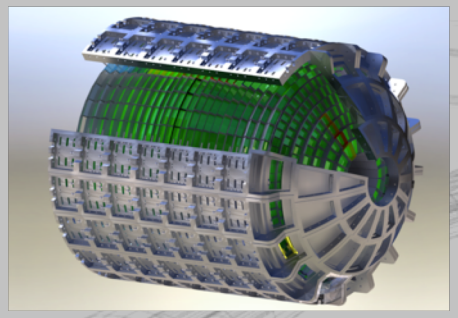
Experimental motivation: CALIFA

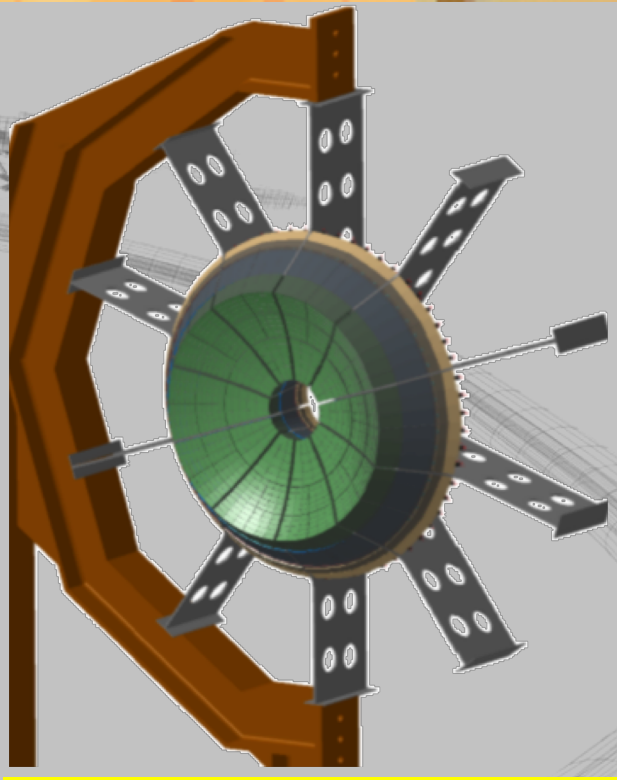




CALorimeter for In-Flight gAmma-rays and protons

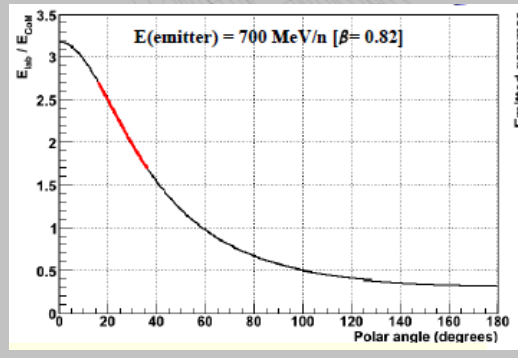
Experimental motivation: CEPA

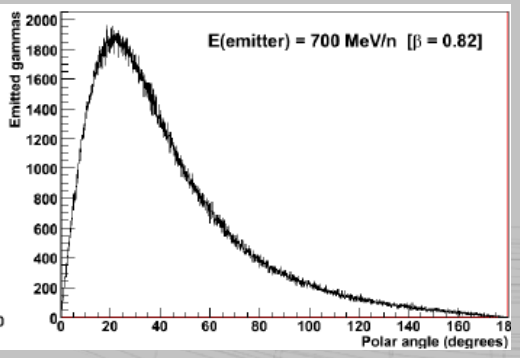




Detect with good energy resolution & high peak efficiency (not so easy!!):

- γ → E < 30 MeV
- p → E < 700 MeV

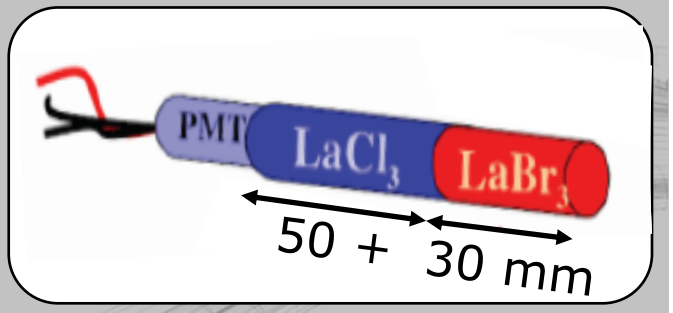


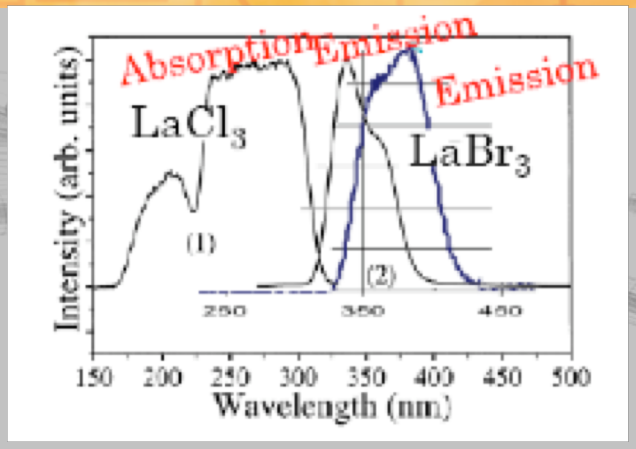


CALIFA Endcap Phoswich Array:

CEPA

The phoswich solution





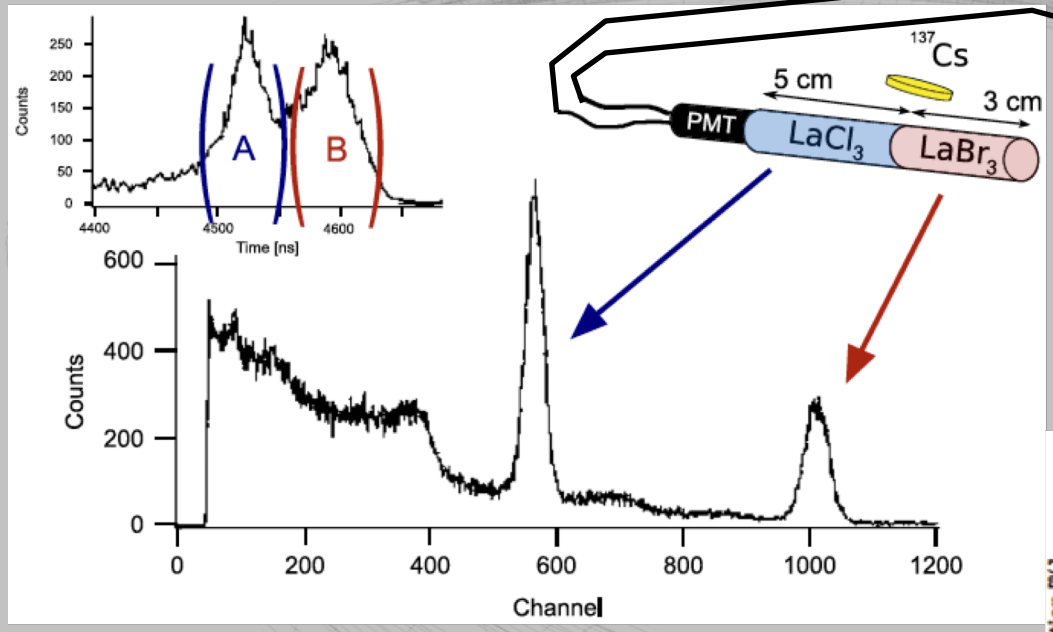
Phoswich:

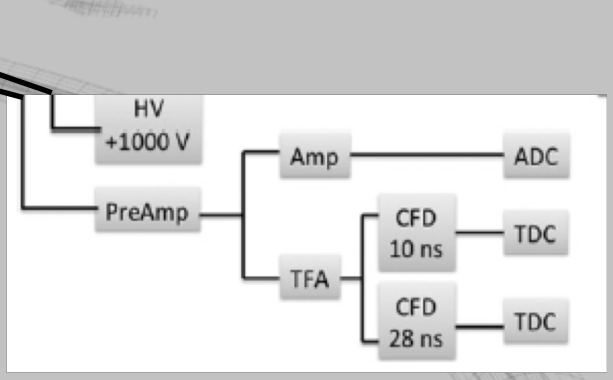
- 2 high-resolution scintillators optically coupled and with a common readout
- Different decay time → possible PSA applications to decouple the energy deposited in both crystals
- Added value: depth of interaction capabilities → Doppler-shift correction & imaging (?)

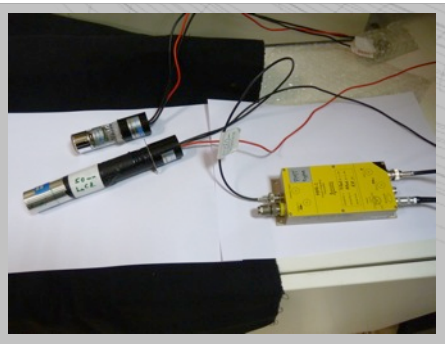
Materials	ΔE/E (% at 662 keV)	Light yield (photons/keV)	Decay time (ns)	$\lambda_{emision}$
$LaBr_3$	2.9	63	16	380 nm
$LaCl_3$	3.8	49	28	350 nm

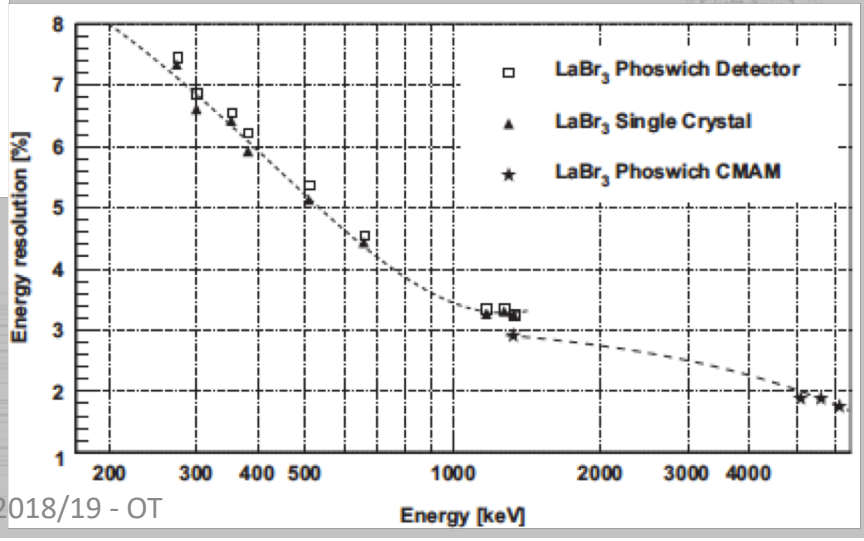
The phoswich solution

- Test with standar γ sources and analog electronics



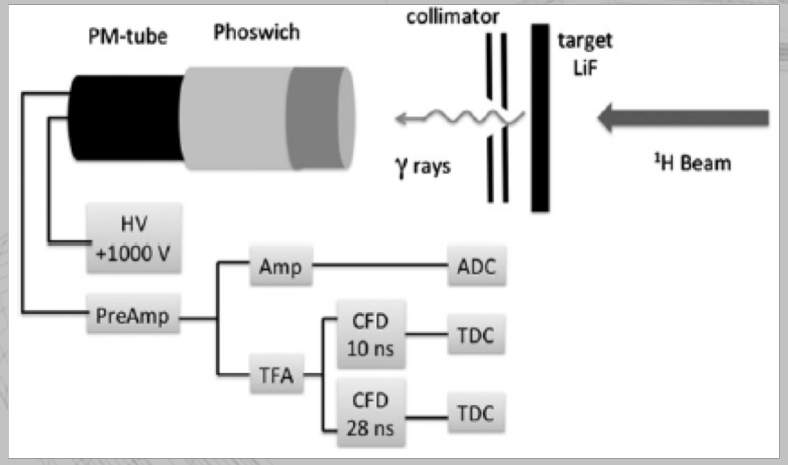


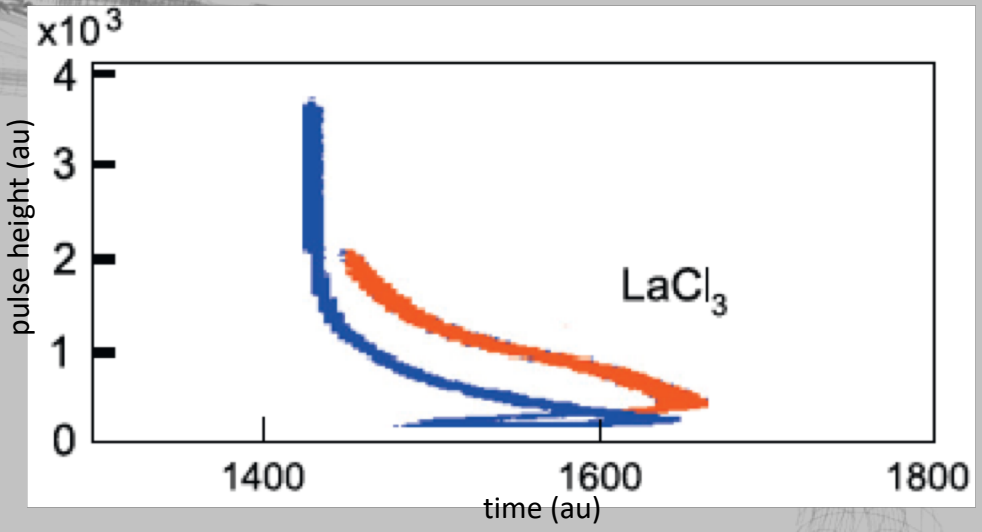




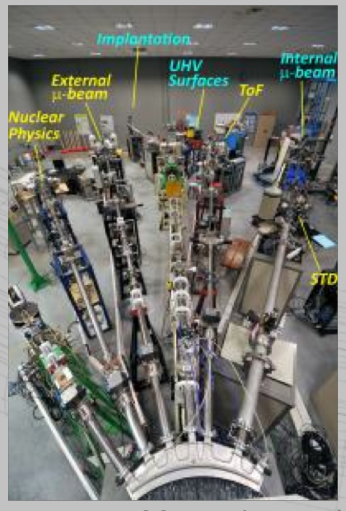
The phoswich solution

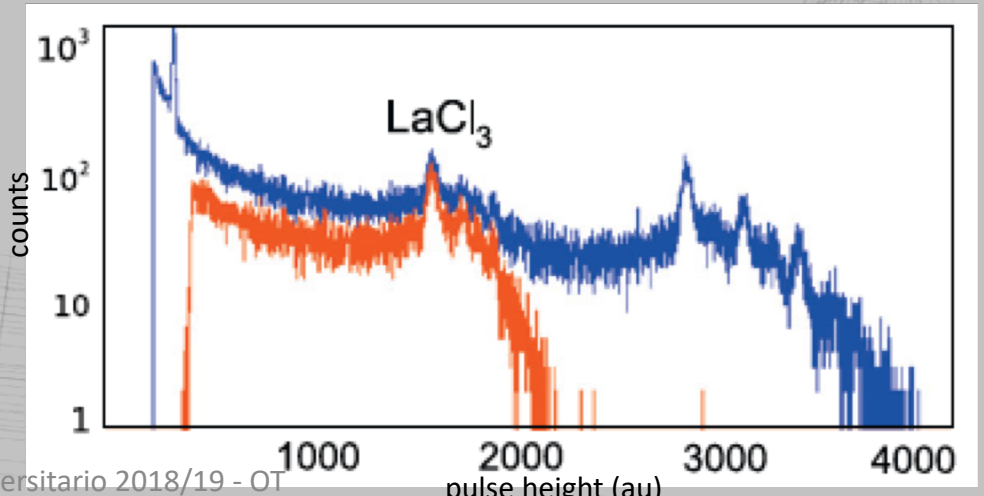
- Test with high-energy γ-rays at CMAM and analog electronics





$^{19}F(p,\alpha\gamma)^{16}O$
[γ-rays at 6.1 MeV]

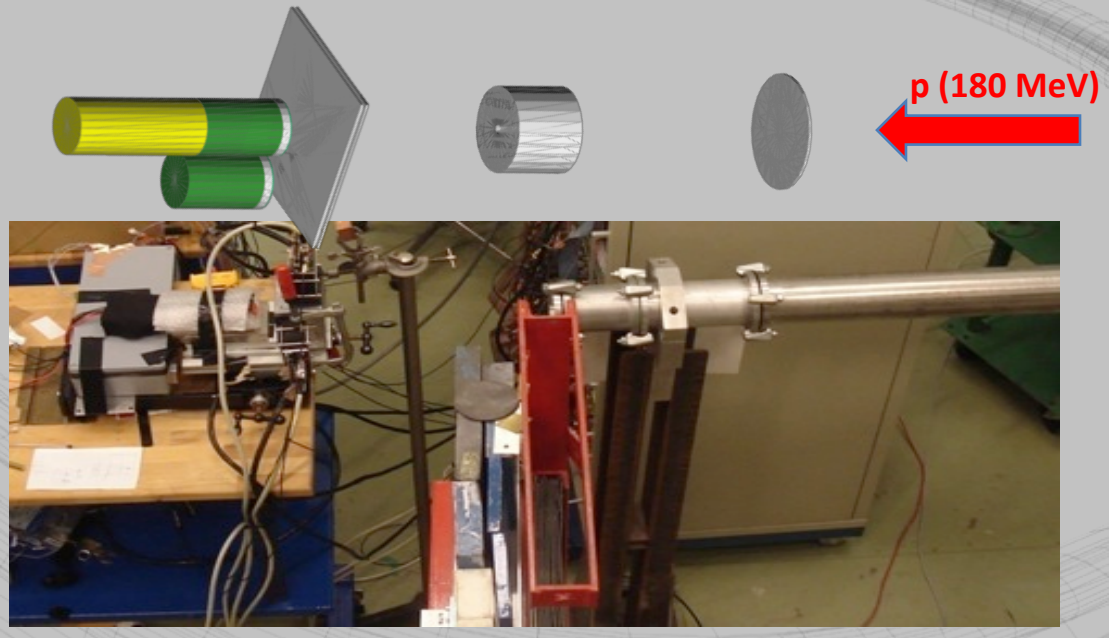




The phoswich solution

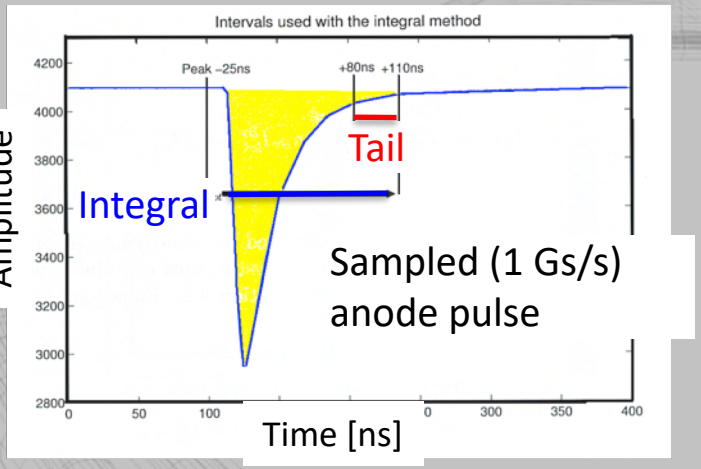
- Test with high-energy protons at TSL and digital electronics

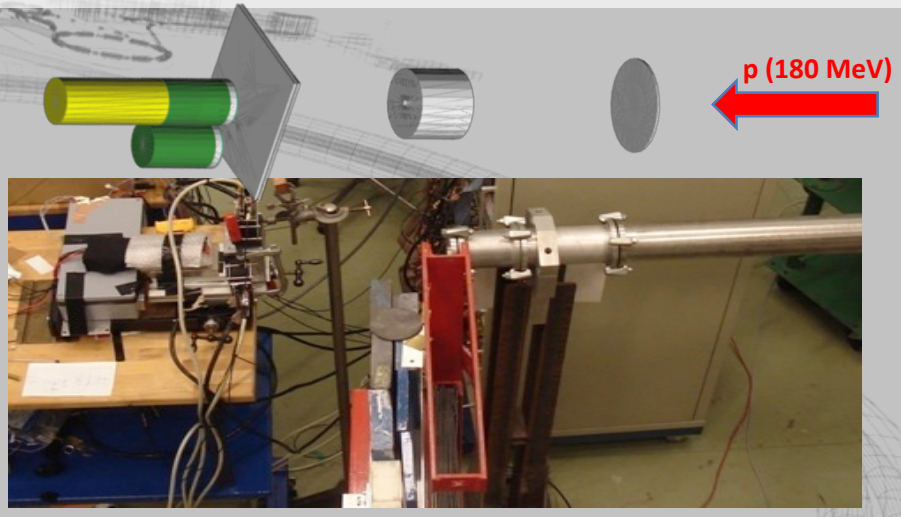
  - 180 and 150 MeV protons



The phoswich solution

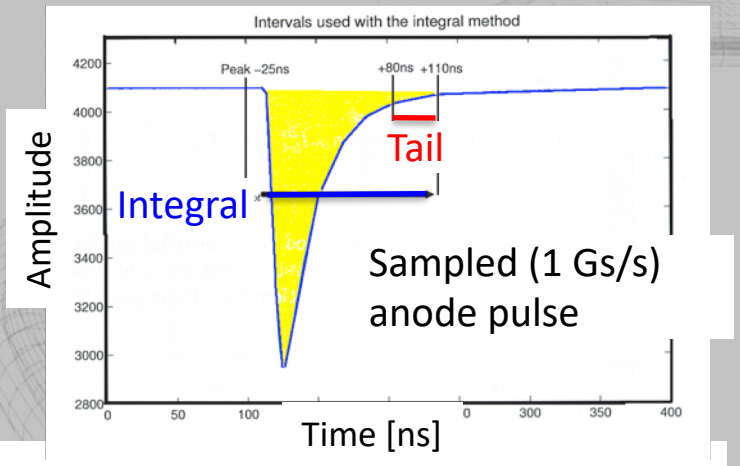
- Test with high-energy protons at TSL and digital electronics

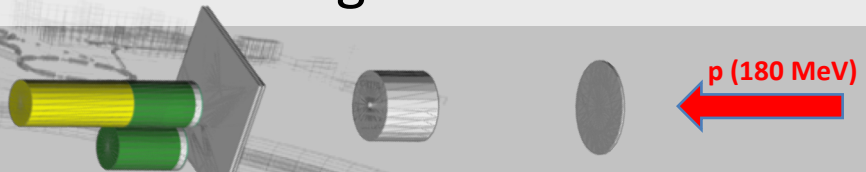


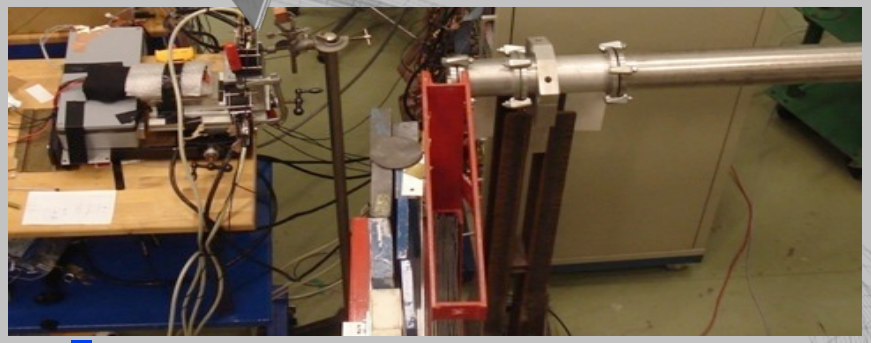


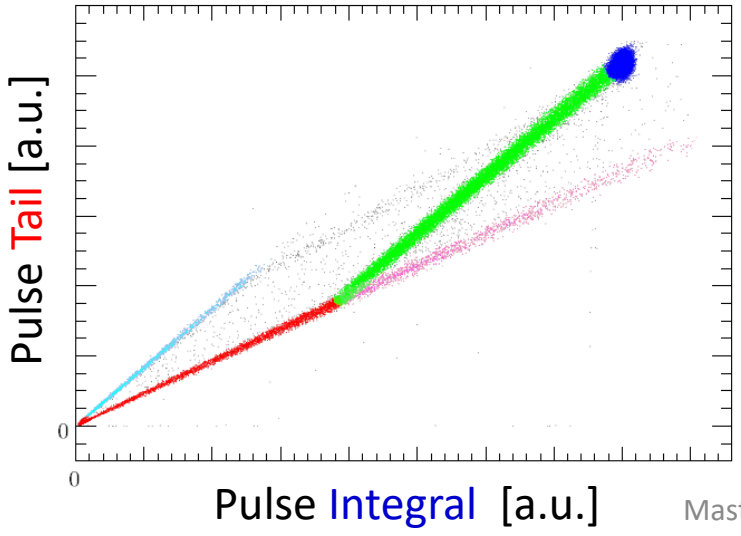
The phoswich solution

- Test with high-energy protons at TSL and digital electronics





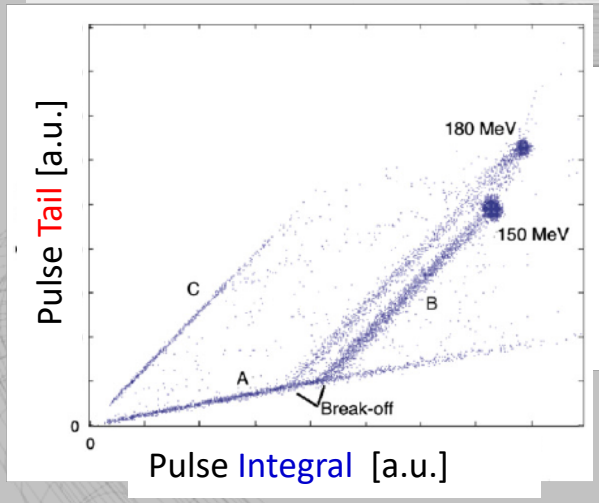




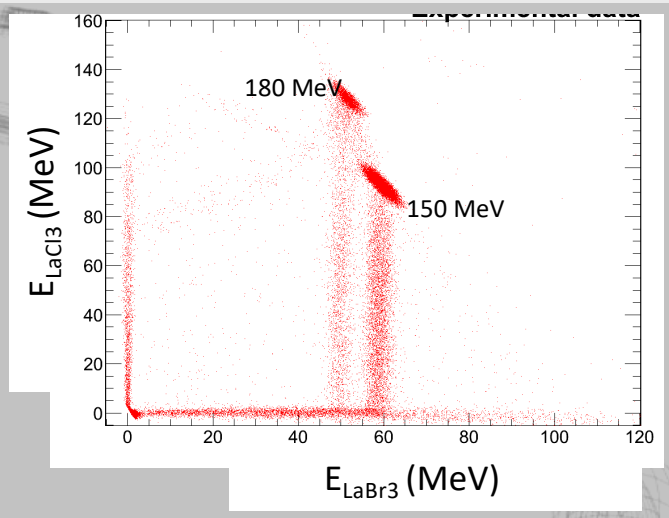
- Proton slowed down in the two xstals and stopped in the 2nd one ($LaCl_3$)
- Proton slowed down in the two crystals and escaped from the 2nd one (or n knock-out)
- Proton slowed down in the 1st crystal and escaped from it
- Proton slowed dowd and stopped in 1st crystal (or p knock-out)
- Proton entered from the side to 2nd crystal

The phoswich solution

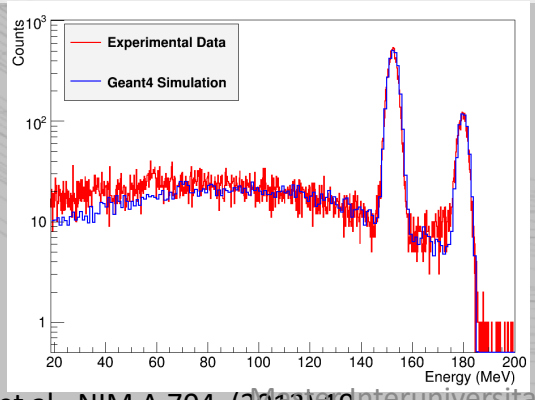
- Test with high-energy protons at TSL and digital electronics

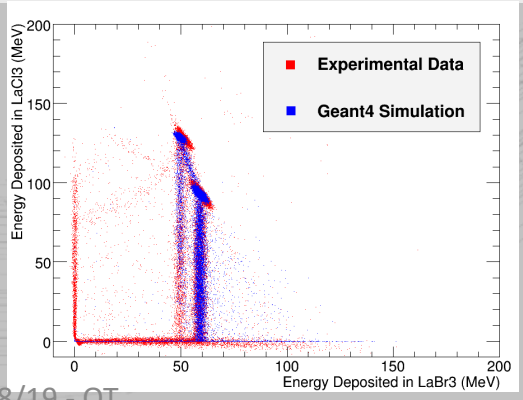


$$\begin{cases} I_{Br}^{total} = \dfrac{I^{tail} - a_{Cl} \cdot I^{total}}{a_{Br} - a_{Cl}} \\ I_{Cl}^{total} = \dfrac{a_{Br} \cdot I^{total} - I^{tail}}{a_{Br} - a_{Cl}} \end{cases}$$



- Geant4 simulations:

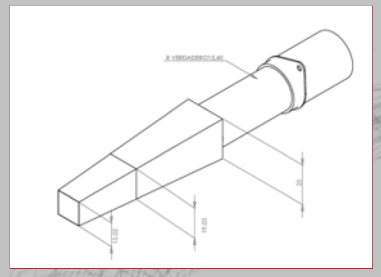


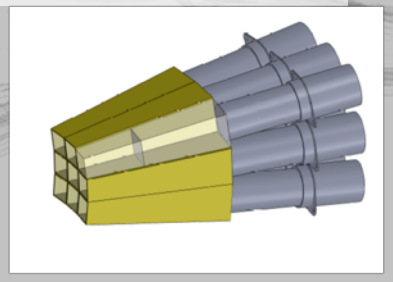


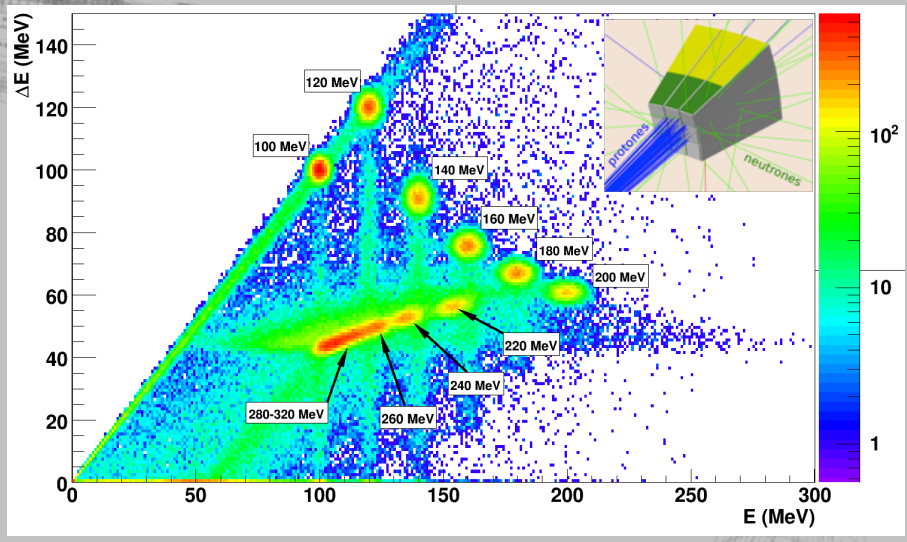
O. Tengblad, T. Nilsson, E. Nacher et al., NIM A 704 (2013) 19

CEPA4: a bigger phoswich array

- What we wanted…

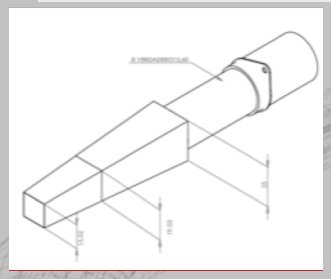


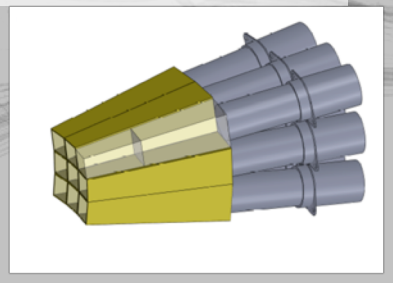




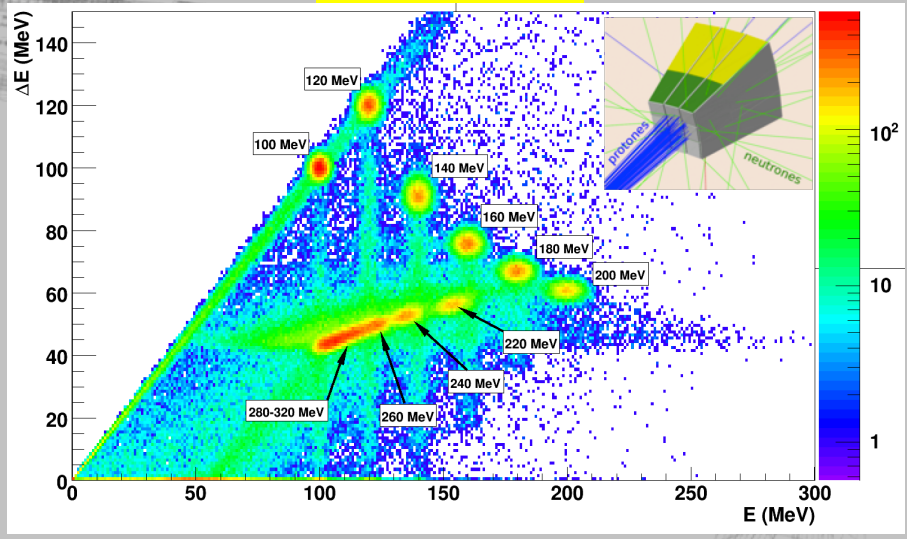
CEPA4: a bigger phoswich array

- What we wanted…

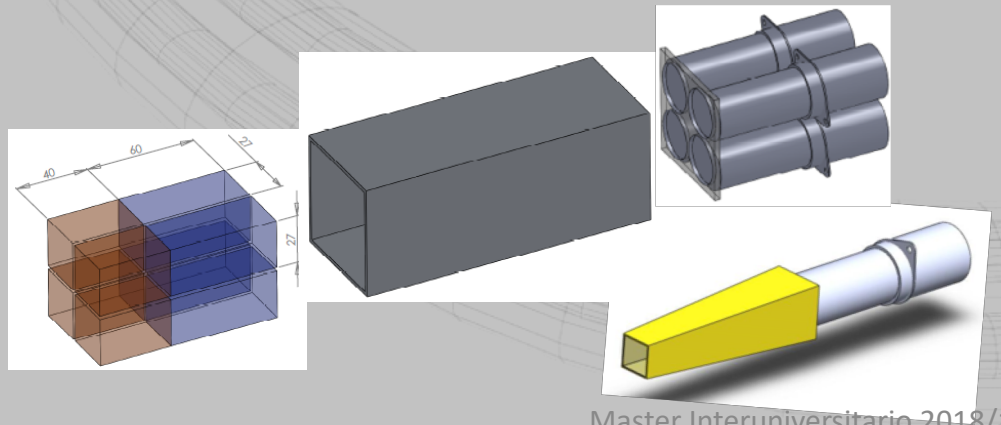




Simulations



- What we got… CEPA4



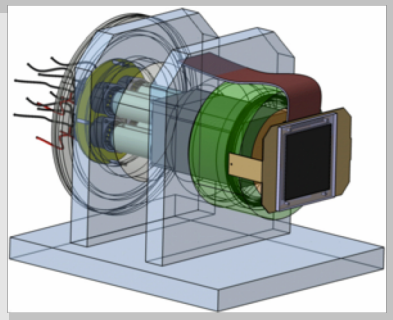
- 4 phoswich units in an Al (0.5mm) can
- $LaBr_3$ (4 cm) + $LaCl_3$ (6 cm) and 27 x 27 mm^2 entrance window
- No Al between the crystals, just 1 mm of Teflon (waterproof?)
- Test the optical insulation and the addback procedure

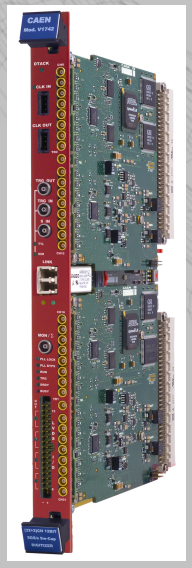
CEPA4: a bigger phoswich array

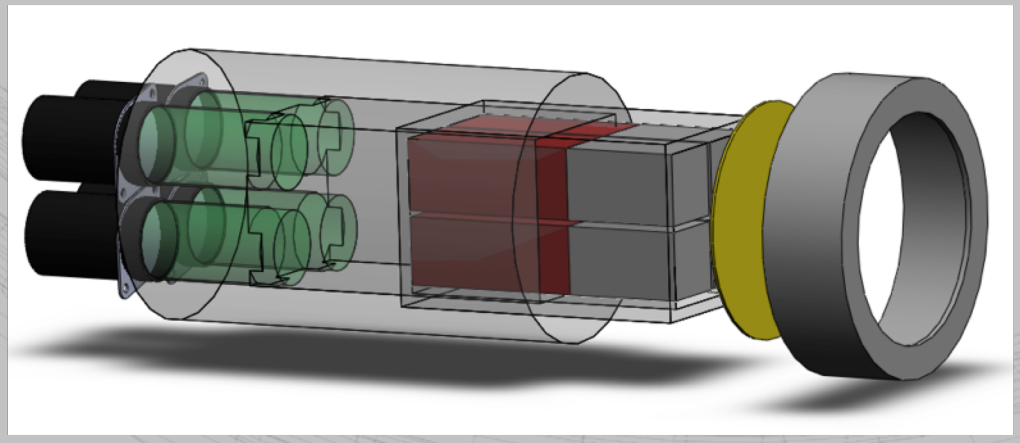
- Readout: 4 Hamamatsu 8-stage PM Tubes R5380 (recently changed to R7600U-200: shorter & square-shaped)

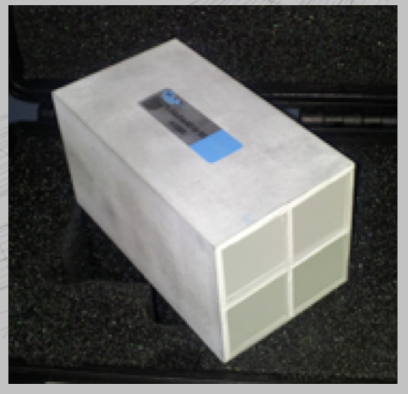
- A DSSD detector (5x5 cm^2) at the entrance face (in vacuum if necessary) to measure the entrance point of the protons or to perform β-del. charged particle / β-del. γ spectroscopy

- A VME CAEN Flash ADC (V1742) to digitize the signals.

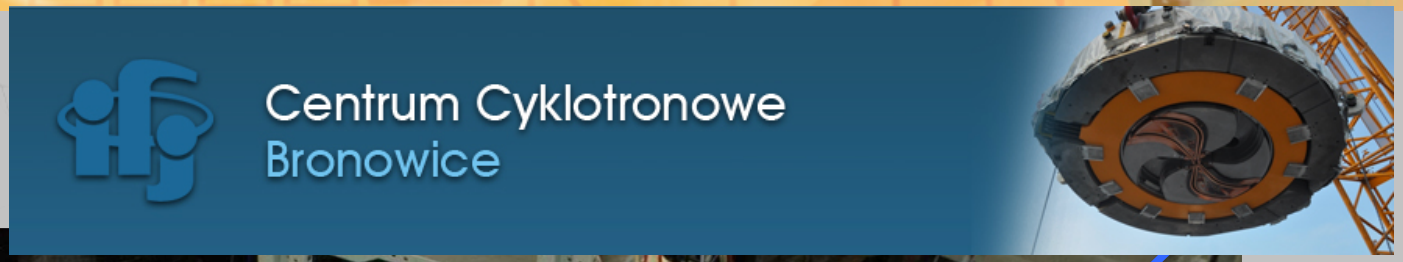


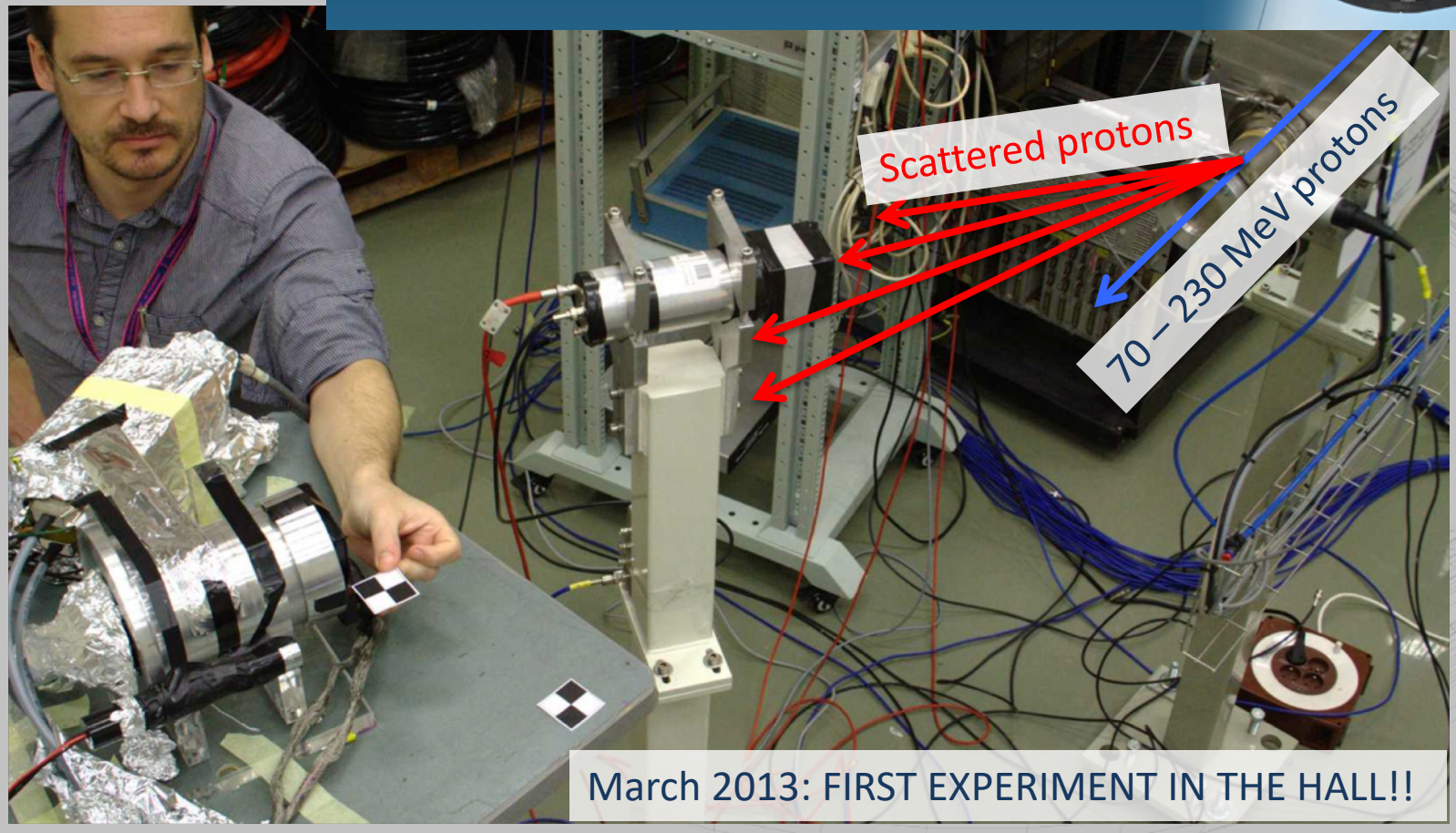




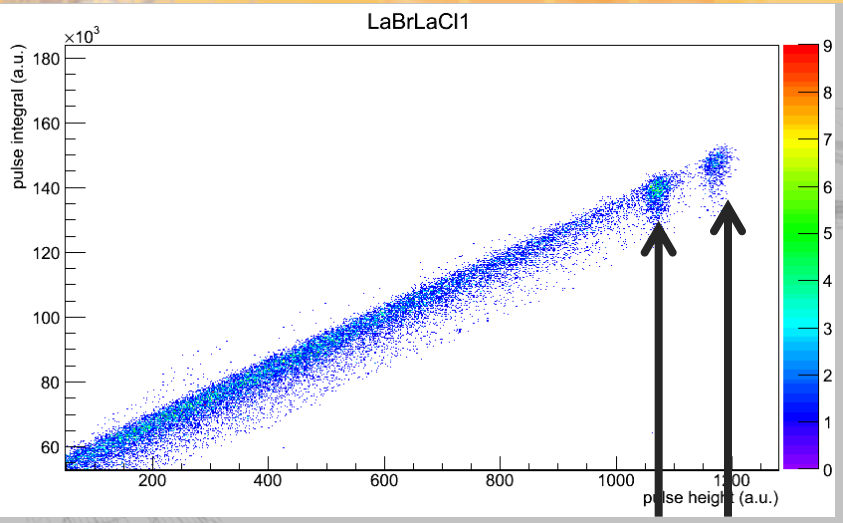


CEPA4: response to protons



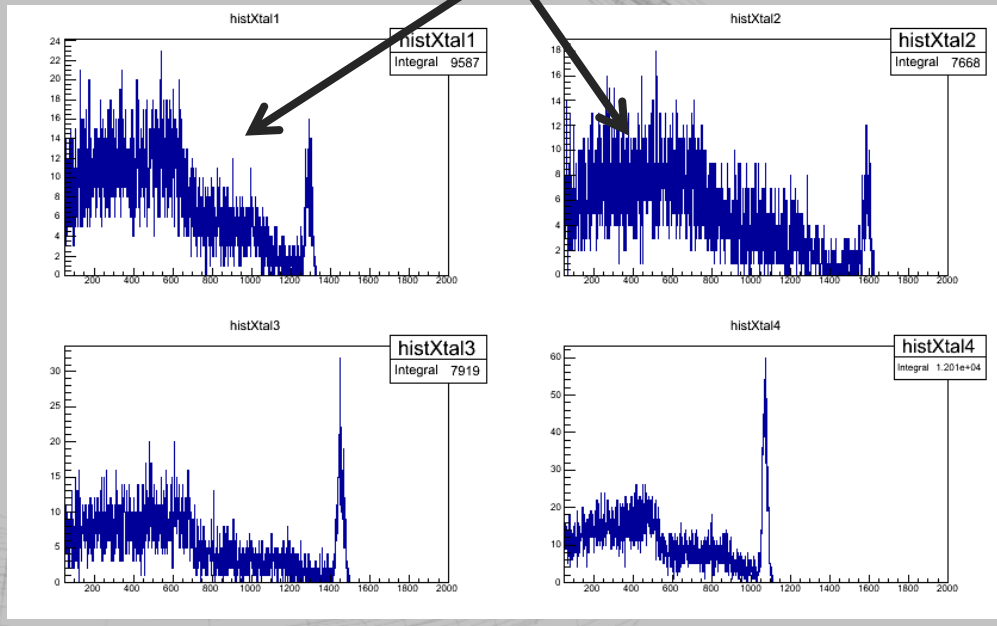


CEPA4: response to protons

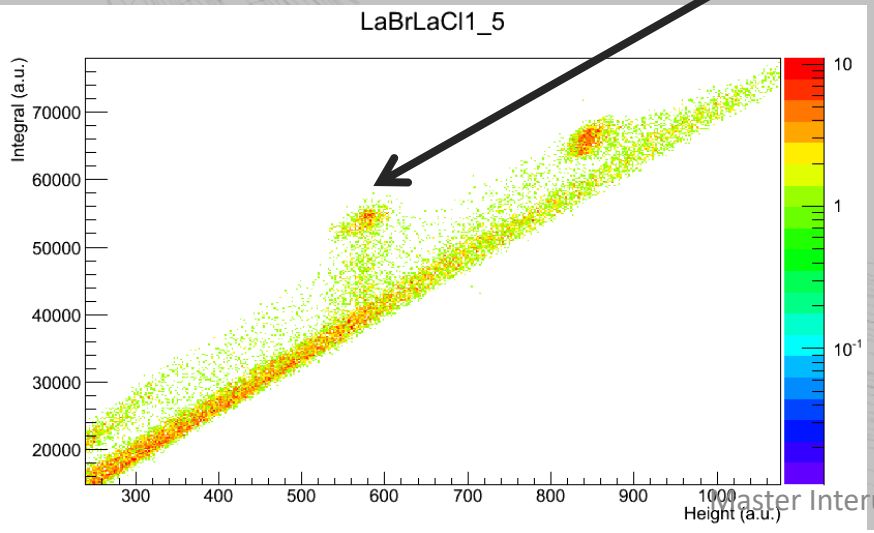


Energy resolution 2.0 – 2.5 %
(nominal beam resolution: 0.7%)

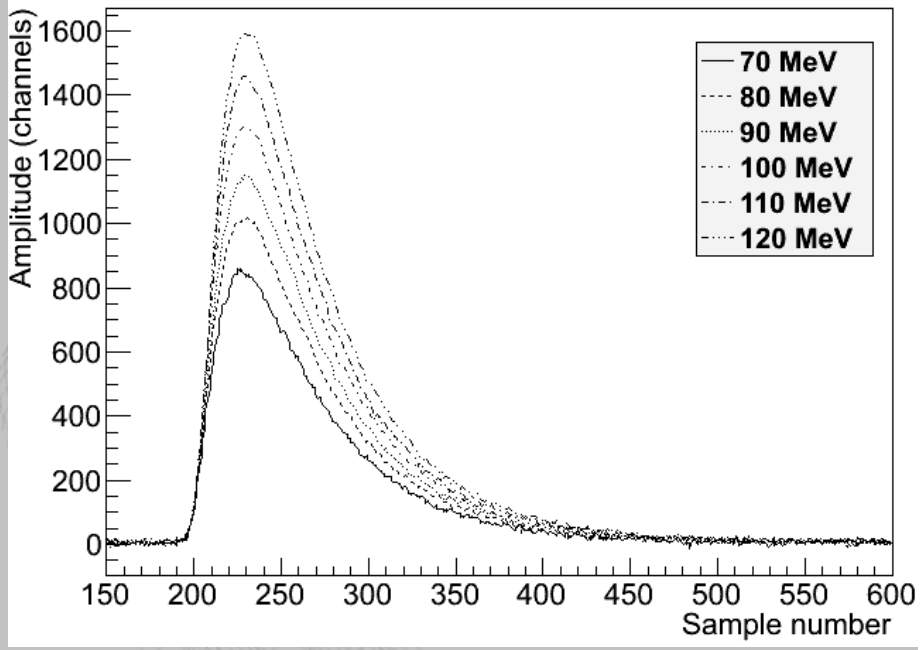
Two crystals receive many more protons scattered at the neighbouring setup



On-line pulse-shape analysis (120, 130 MeV)
Xtal5 (shorter): Energy beyond punch through



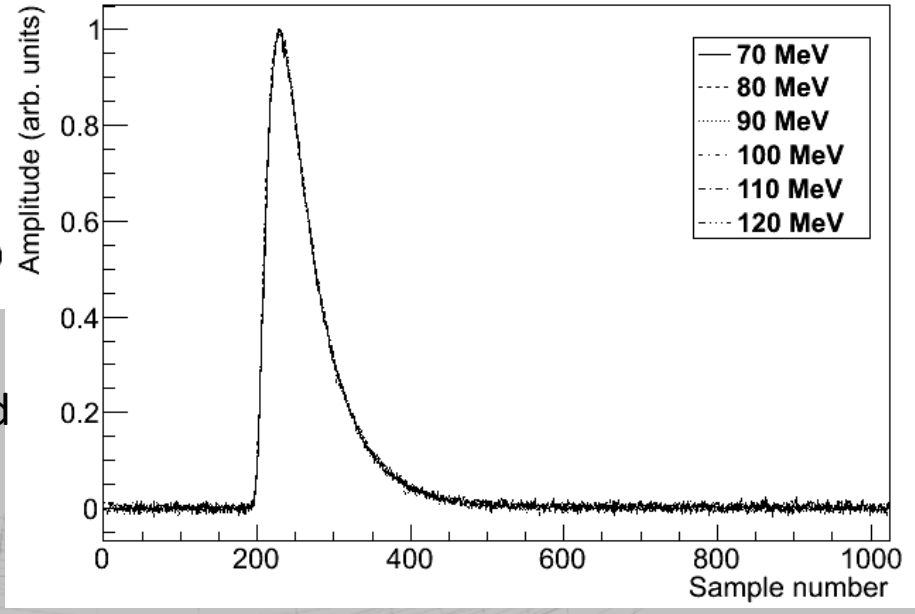
CEPA4: response to protons



Proton traces from the Flash ADC de-noised using a wavelet decomposition and filter procedure

(M. Mårtensson master thesis)

The same, normalized to the energy



Data Analysis at 3 different levels:

1 – Total Integral vs Height

2 - Solve a set of linear equations to find E_{LaBr3} and E_{LaCl3}

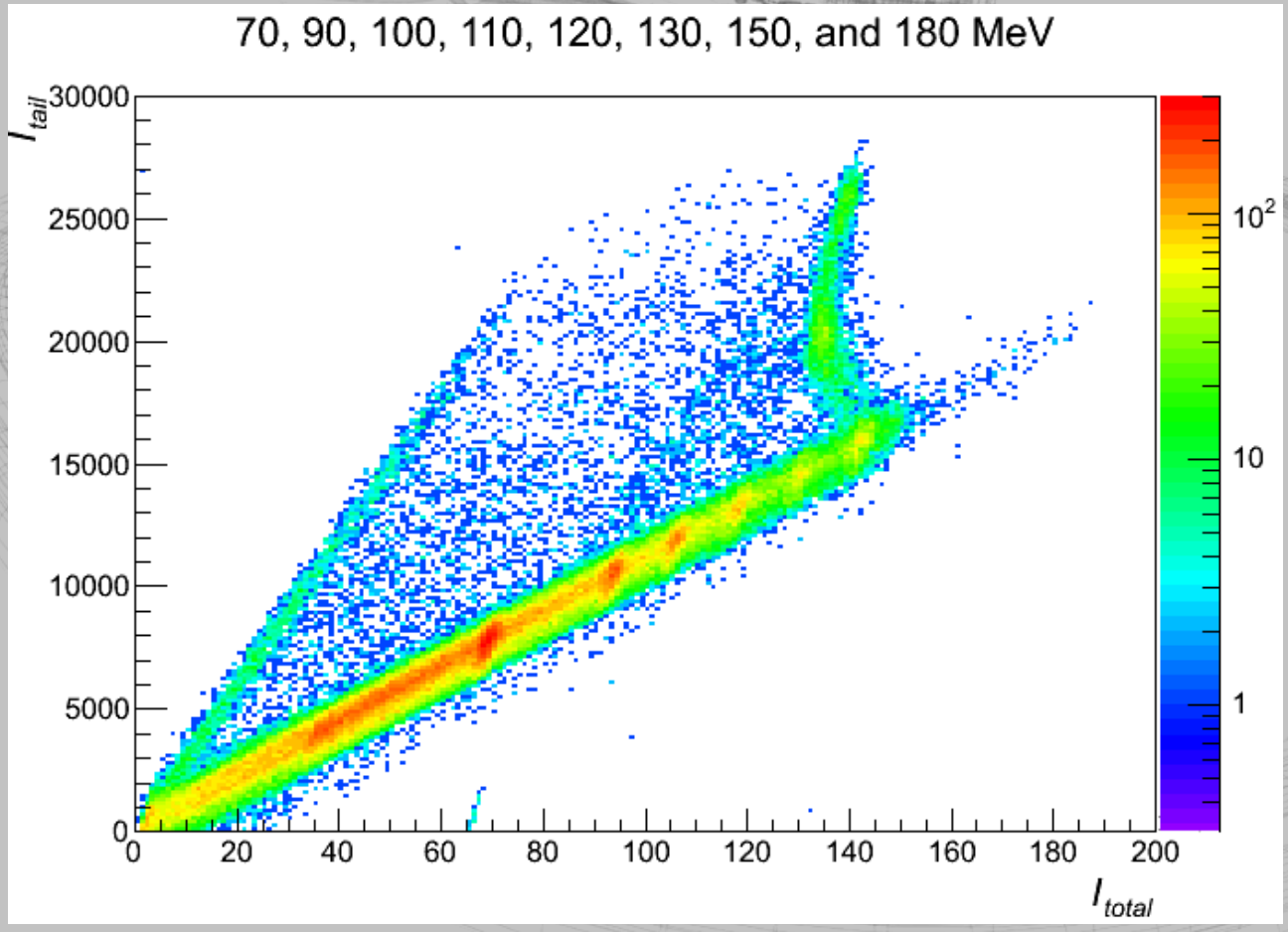
(→ See: O. Tengblad, T. Nilsson, E. Nacher et al., NIM A 704 (2013) 19)

3 – Project on the appropriate lines depending on the energy region (calibration?)

(→ Analyze the energy resolution & the response after the total punch-through)

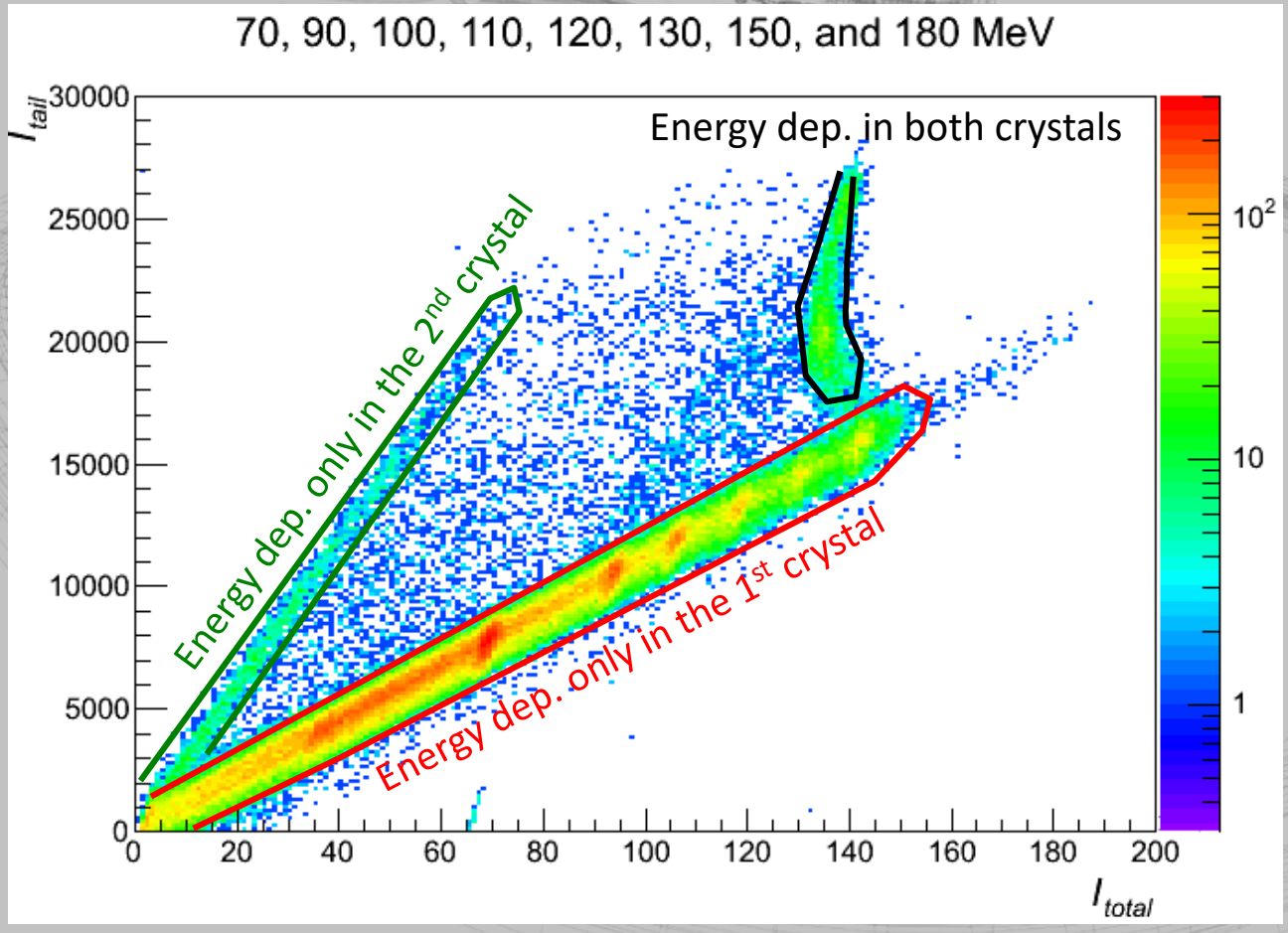
CEPA4: response to protons

1 - Integrals: tail vs total



CEPA4: response to protons

1 - Integrals: tail vs total

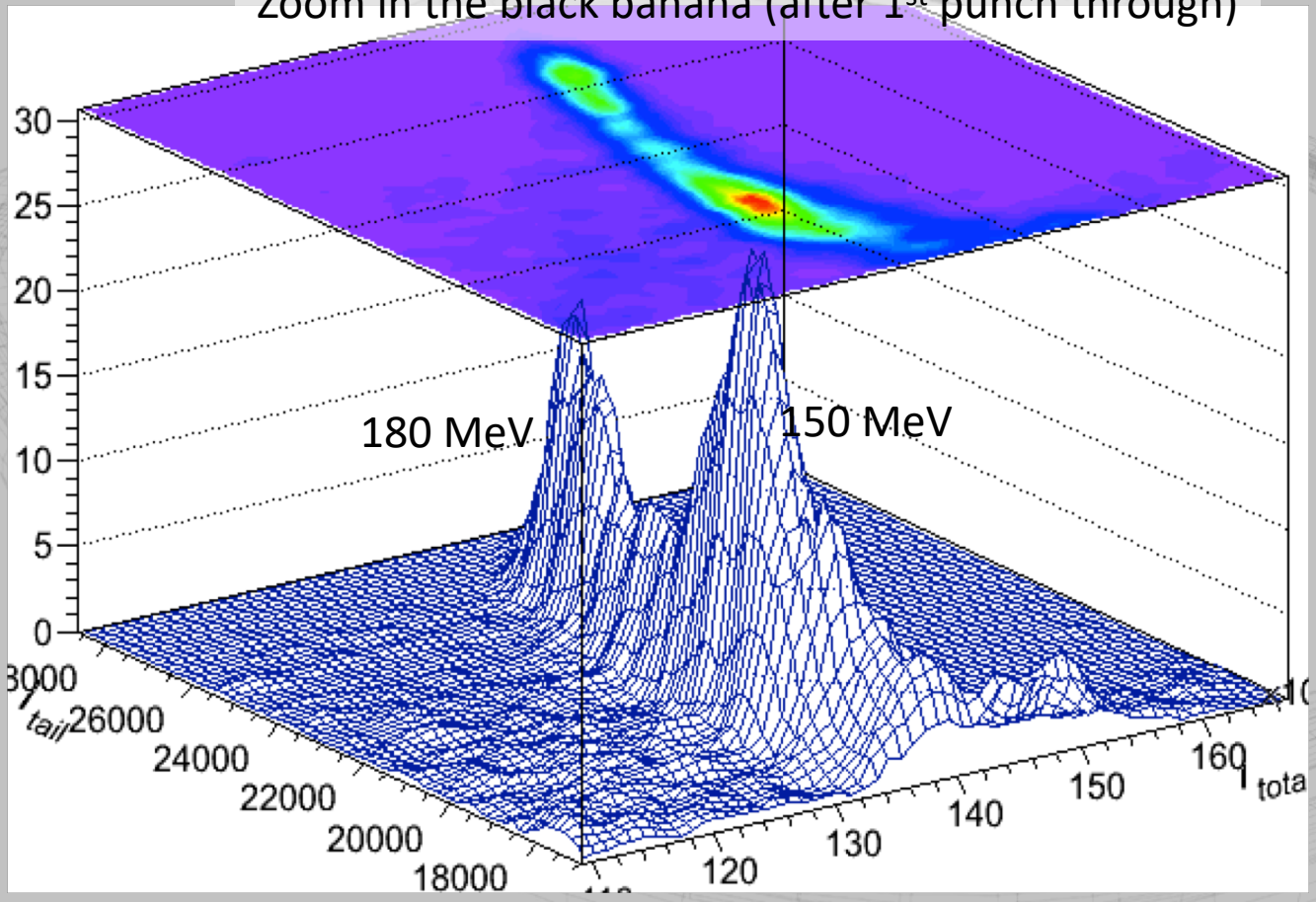


$$\begin{cases} I_{Br}^{tail} = a_{Br} \cdot I_{Br}^{total} \\ I_{Cl}^{tail} = a_{Cl} \cdot I_{Cl}^{total} \end{cases}$$

CEPA4: response to protons

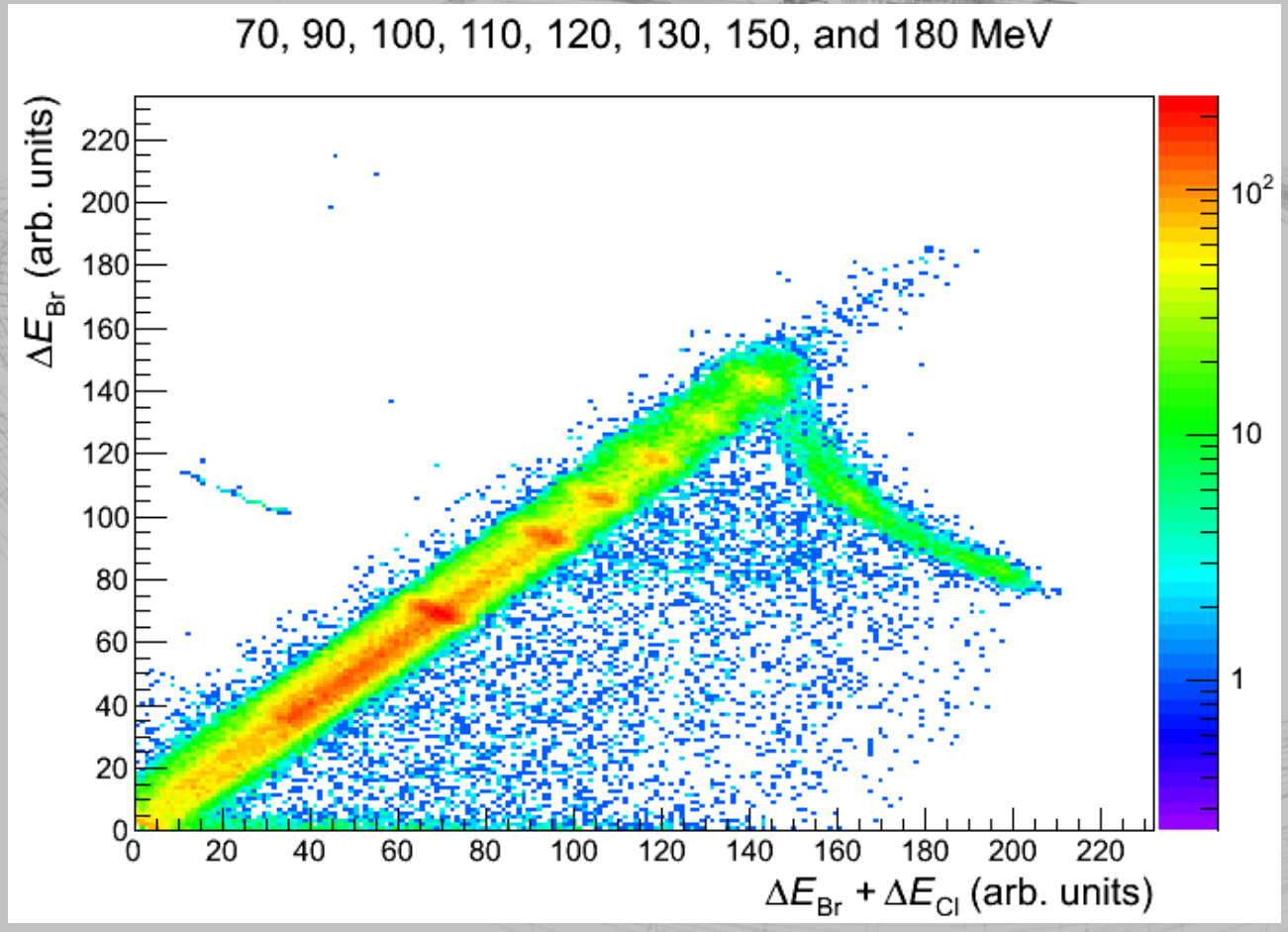
1 - Integrals: tail vs total

Zoom in the black banana (after 1st punch through)



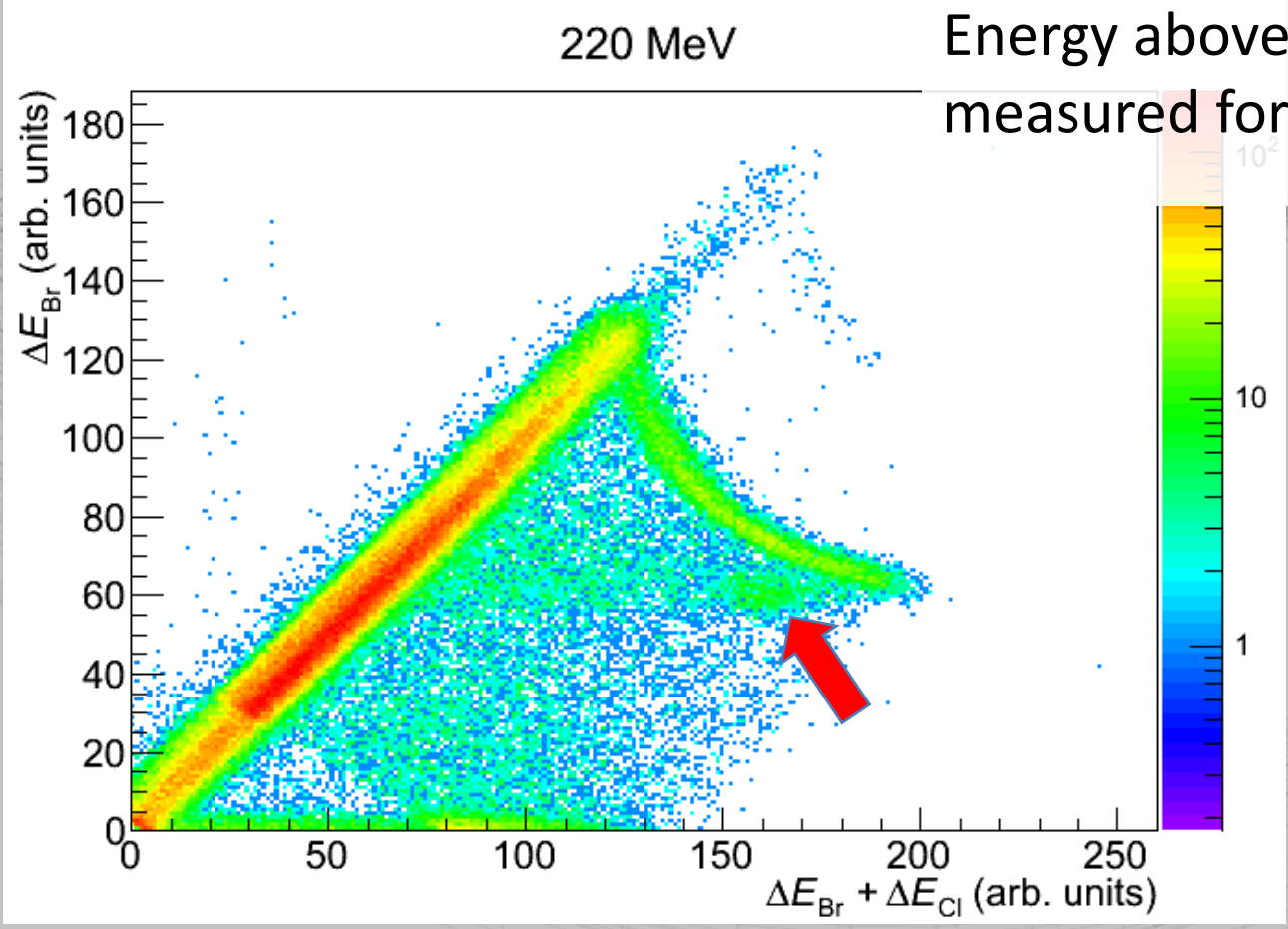
CEPA4: response to protons

2 - E_{LaBr3} vs E_{tot}



CEPA4: response to protons

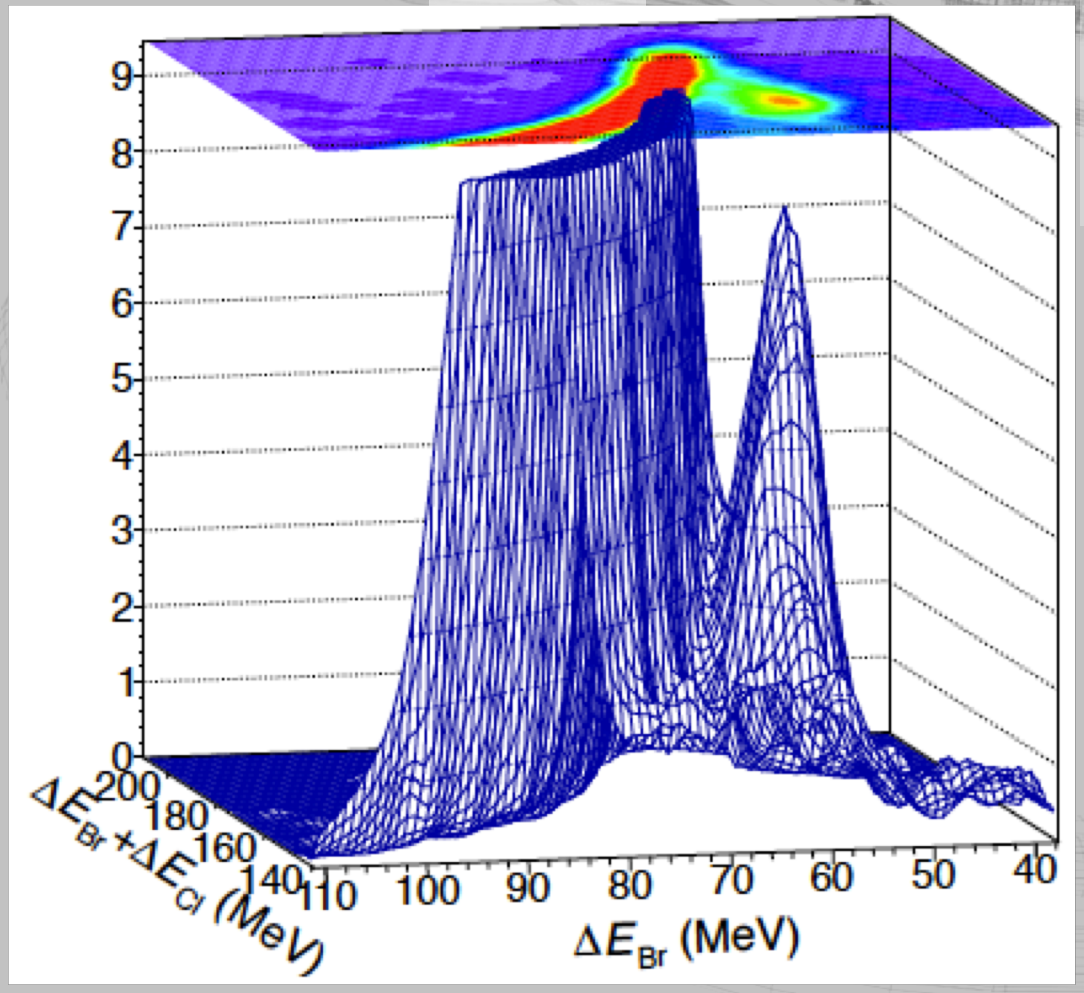
2 - E_{LaBr3} vs E_{tot}



Energy above punch through measured for the first time!!

CEPA4: response to protons

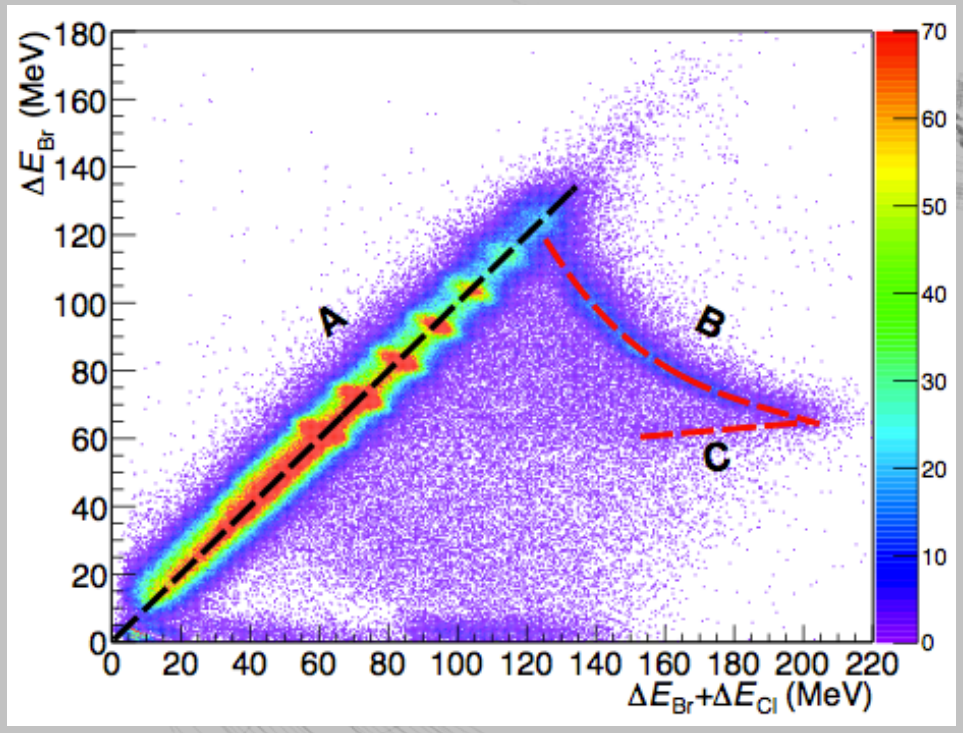
220 MeV



2 - E_{LaBr3} vs E_{tot}

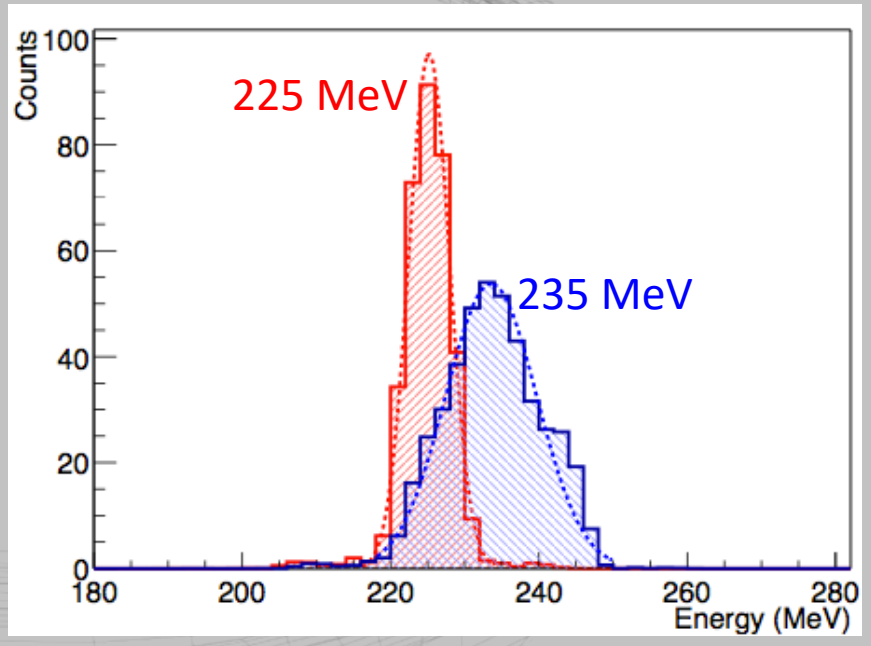
Energy above punch through measured for the first time!!

CEPA4: response to protons

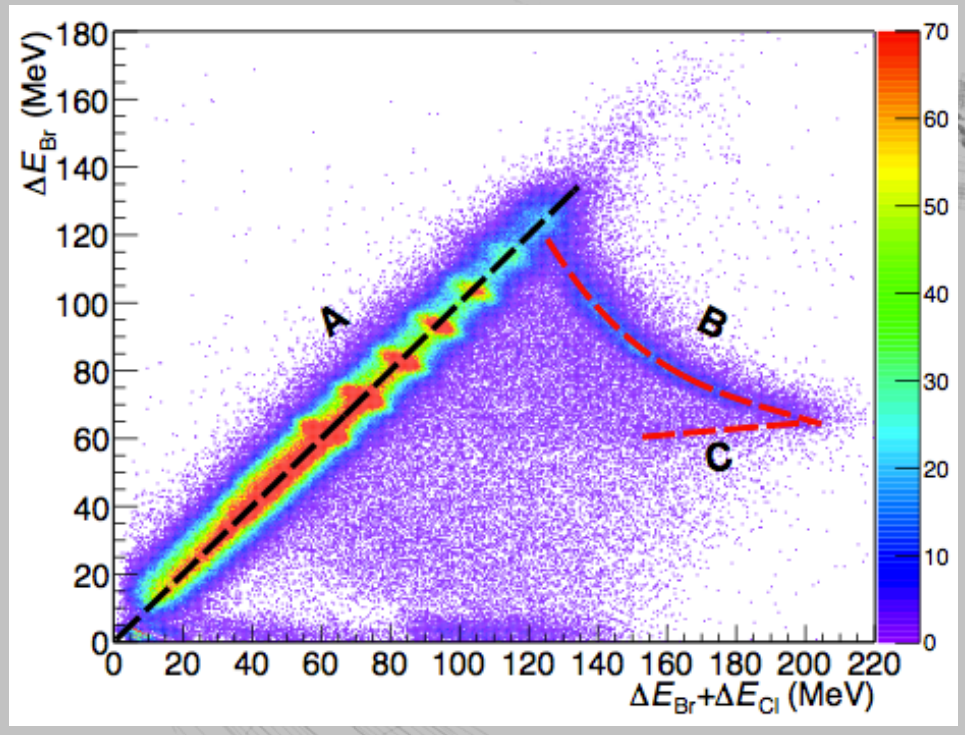


3 - Calibration:

response beyond 200 MeV

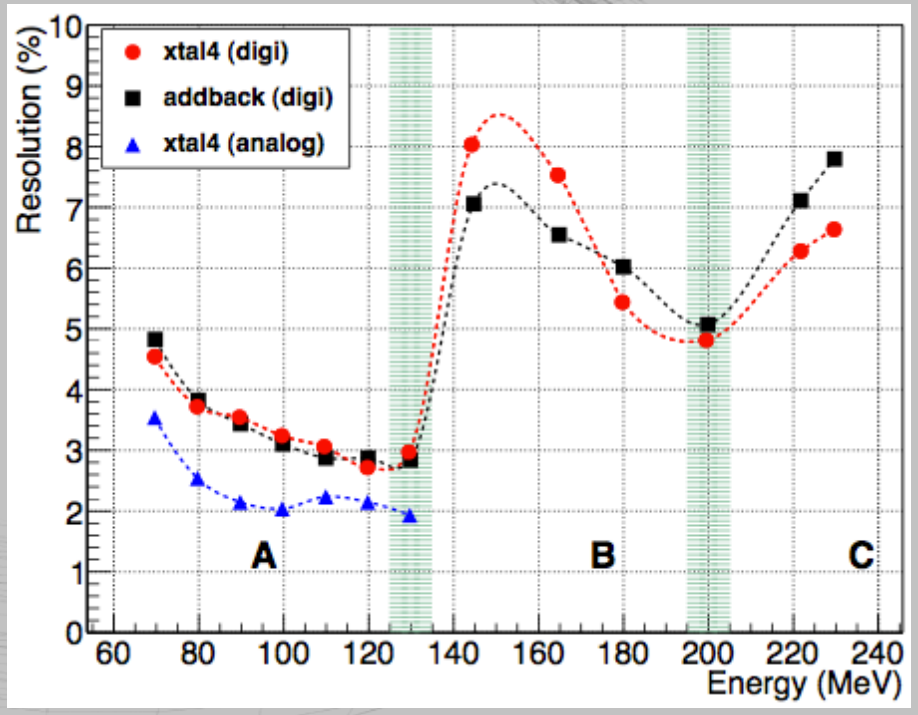


CEPA4: response to protons

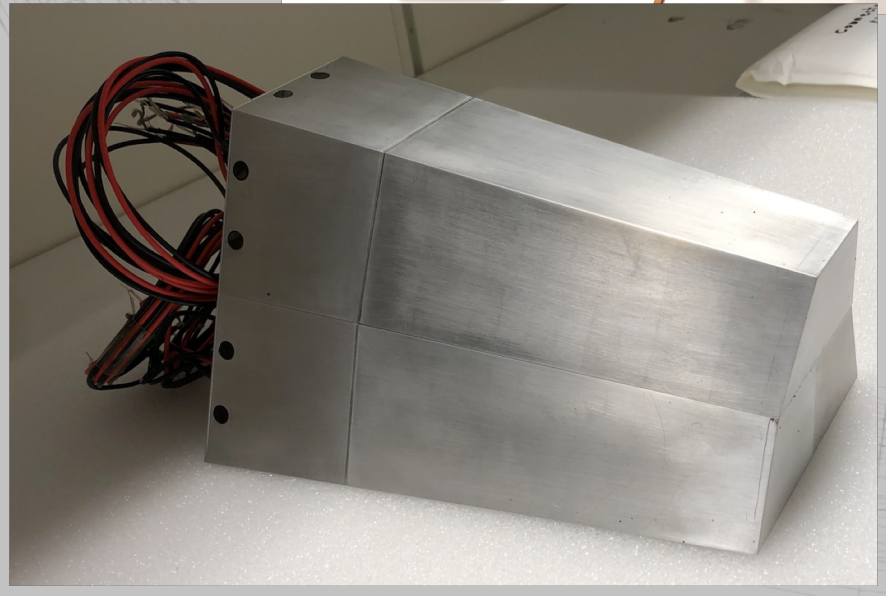


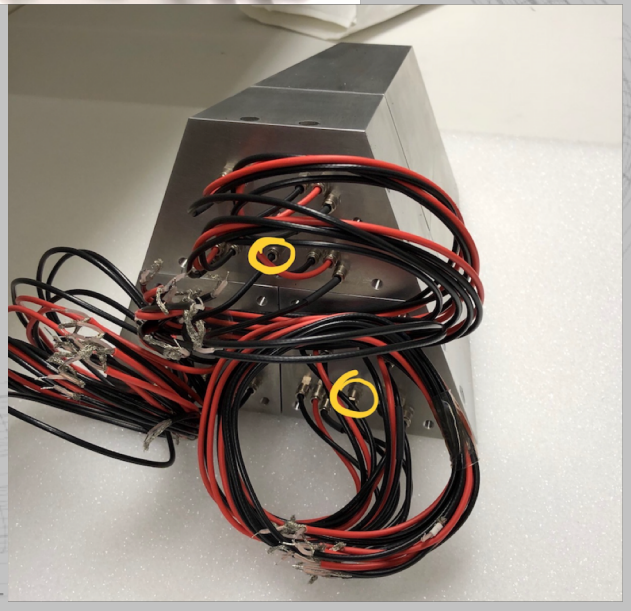
3 - Calibration:

energy resolution



CEPA 2018





Summary & Conclusions

1 – CEPA4, a new high-resolution phoswich array with Good optical insulation and moisture-proof so far, even with no Aluminum casing for the individual crystals.

2 – CEPA4 has been tested with proton beams (70-230 MeV).

3 – The PSA procedure has been tested and has provided good results even beyond the total punch-through energy. We have a reliable method to calibrate the detector by regions.

4 – The energy resolution for high-energy protons

5 – With a DSSD at the front entrance of the setup it can be used for β-del proton /β-del α/β-delayed γ spectroscopy

THANK YOU!!

E. Nácher, A. Perea, G. Ribeiro, J. Sánchez del Río, O. Tengblad
Instituto de Estructura de la Materia – CSIC, Madrid

M. Mårtensson, A. Heinz
Chalmers University, Göteborg