Innovative solutions for the CALIFA forward endcap

J. Cederkal, for the CALIFA collaboration

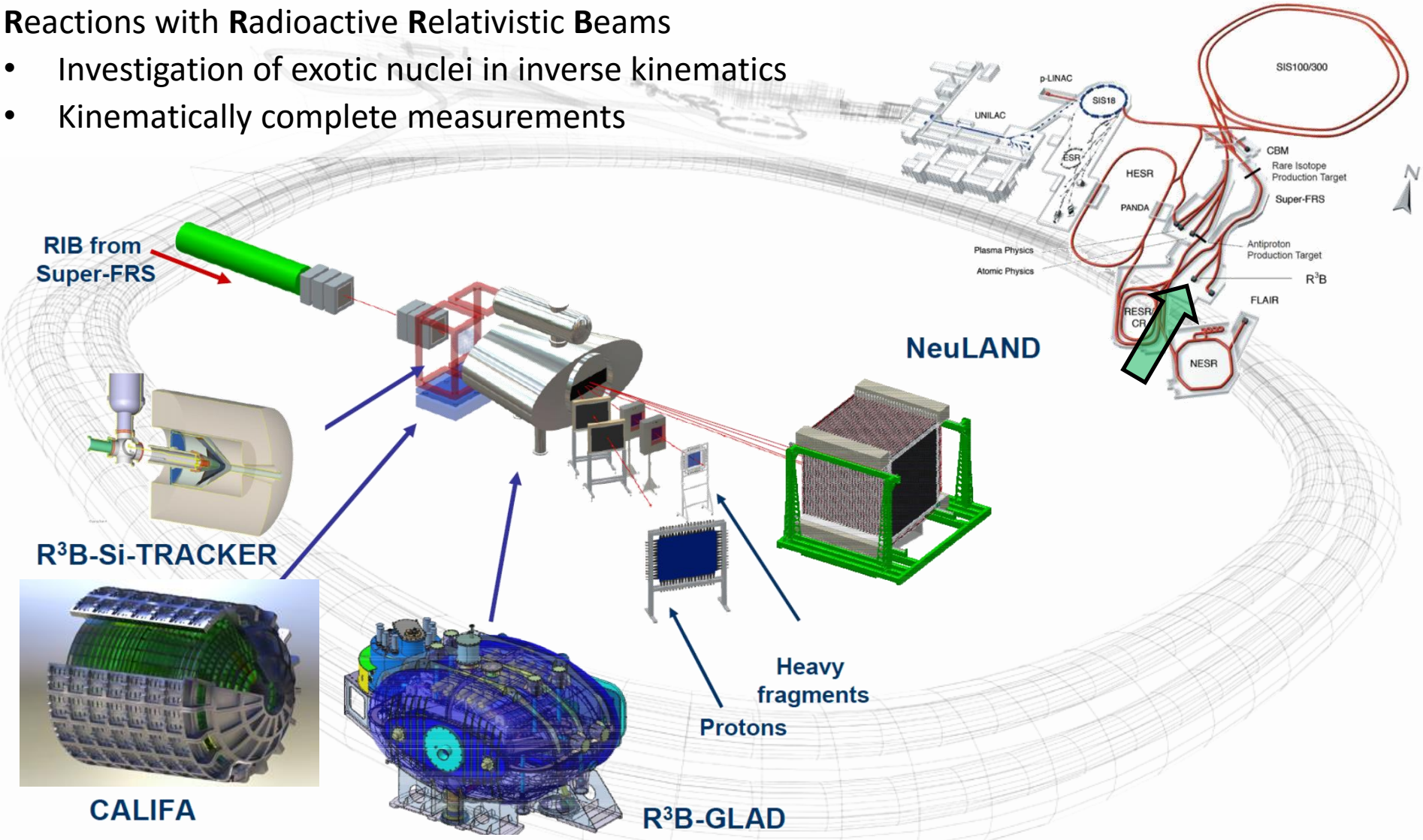
Outlook

- Introduction: R3B at FAIR
- CALIFA
- Forward endcap: CEPA
- Test results with prototypes (PHOSCYL, CEPA4)
- The iPhos concept
- Summary and conclusions

R3B at FAIR

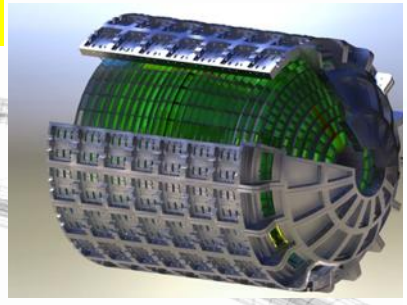
Reactions with **R**adioactive **R**elativistic **B**eams

- Investigation of exotic nuclei in inverse kinematics
- Kinematically complete measurements



CALIFA

CALorimeter for In-Flight gAmma-rays and protons



Barrel:

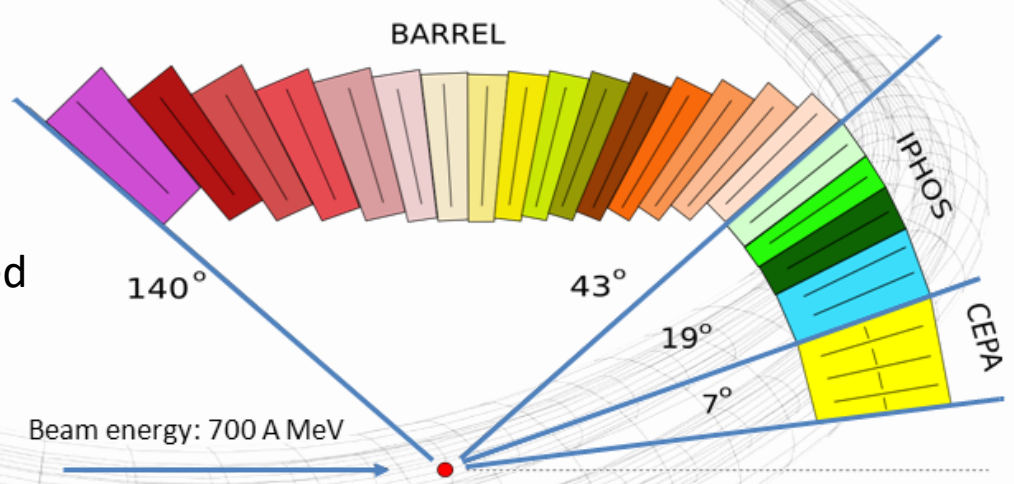
- 1952 CsI(Tl) scintillation crystals (0,7 μs + 3,3 μs) + LAAPD readout
- Direct energy measurement of stopped protons up to ~300 MeV

iPhos:

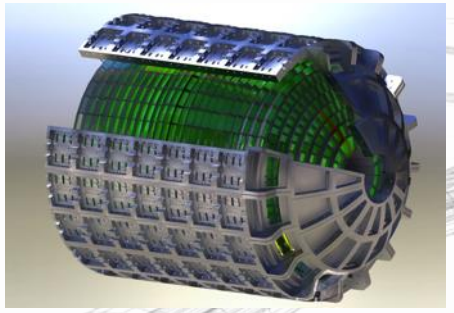
- 512 CsI(Tl) crystals + LAAPD readout
- Full energy reconstruction of punched through protons by PID

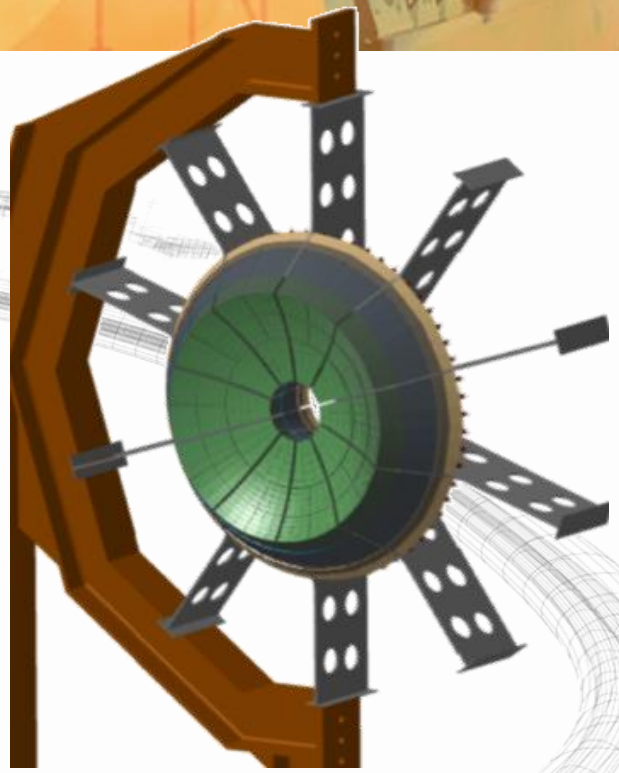
CEPA:

- 96 $LaBr_3$ (16 ns) + $LaCl_3$ (28 ns) Phoswich detectors + PMT readout



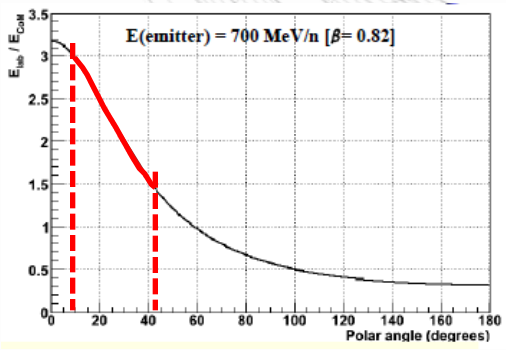
The CALIFA forward endcap

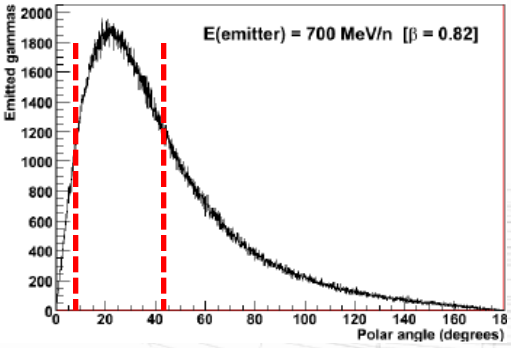




Detect with good energy resolution & high peak efficiency (not so easy!!):

- γ → E < 30 MeV
- p → E < 300 MeV

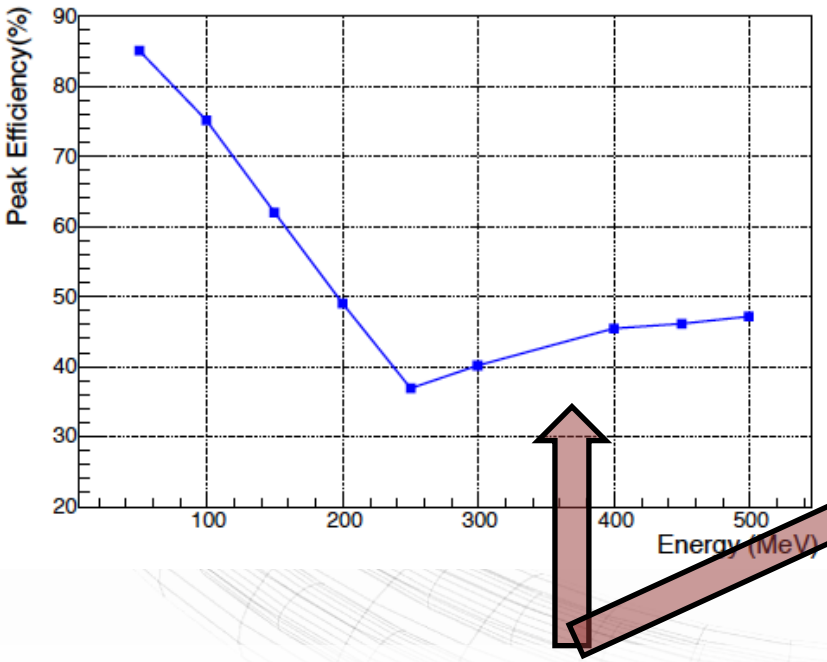


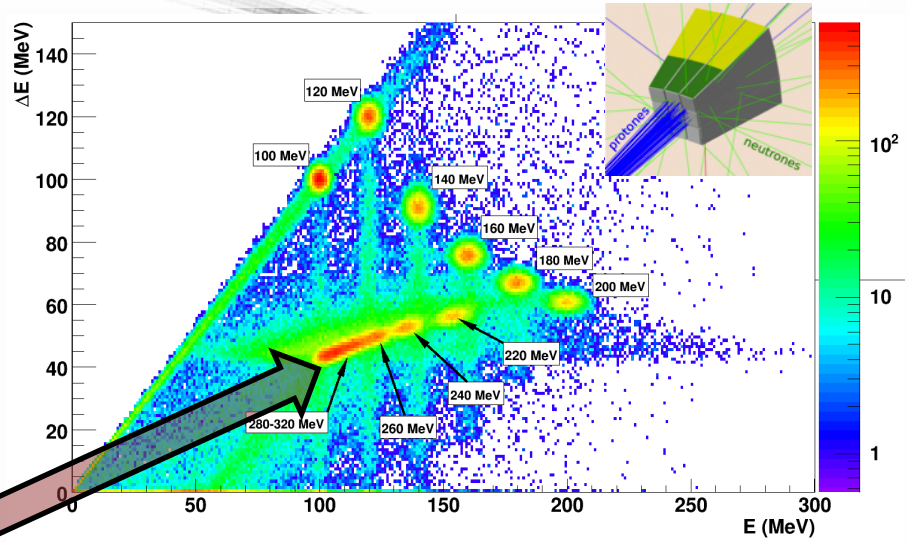


At β=0.82 the Doppler shift within the endcap angular acceptance is up to a factor of 3, and about 85% of the total number of gammas go to the endcap.

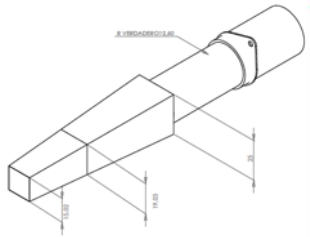
CEPA4: a bigger phoswich array

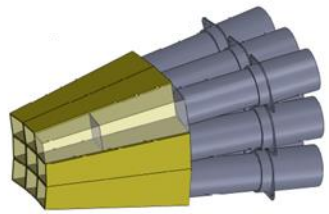
- If we use long crystals to stop the protons the energy resolution is good but the efficiency drops very rapidly with energy (nuclear reactions!)
- Geant4 simulations -> 2 benefits from phoswich: full energy reconstruction without loosing efficiency and nuclear reaction background cleaning.



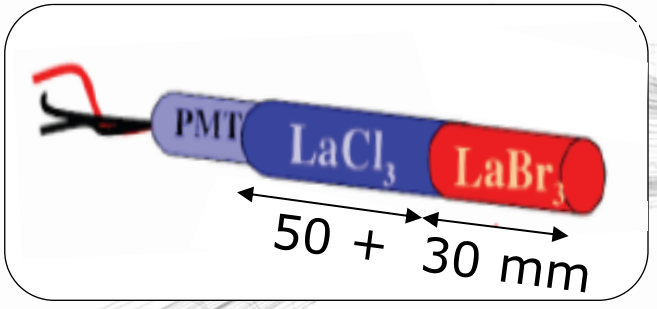


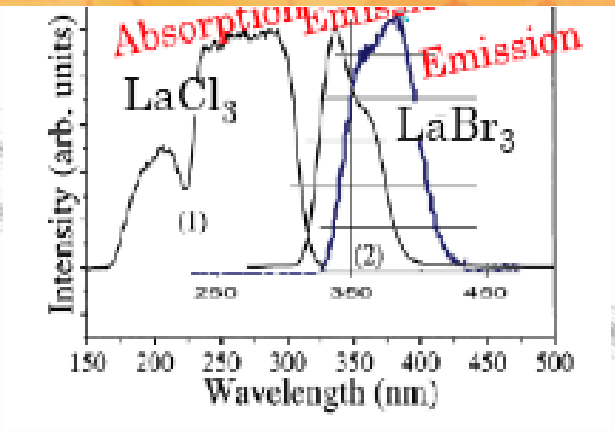
- After punch through we stop loosing efficiency…, at the expense of a worse energy resolution





The phoswich solution

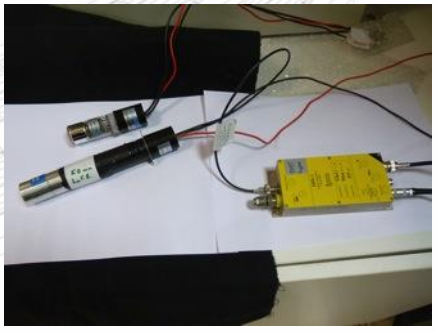




Phoswich:

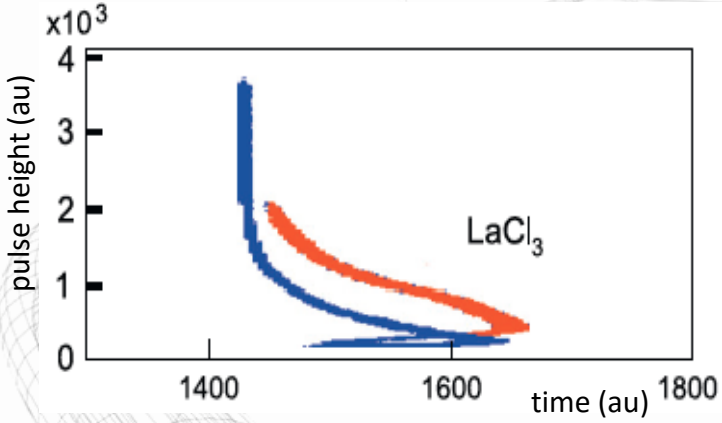
- 2 high-resolution scintillators optically coupled and with a common readout
- Different decay time → possible PSA applications to decouple the energy deposited in both crystals
- Added value: depth of interaction capabilities → Doppler-shift correction & imaging (?)

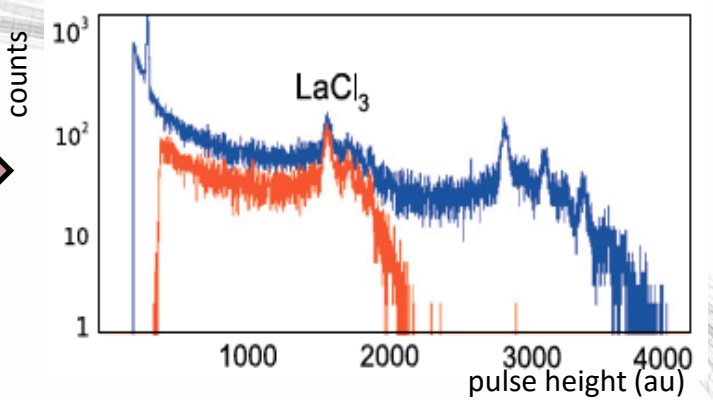
Materials	ΔE/E (% at 662 keV)	Light yield (photons/keV)	Decay time (ns)	$\lambda_{emision}$
$LaBr_3$	2.9	63	16	380 nm
$LaCl_3$	3.8	49	28	350 nm



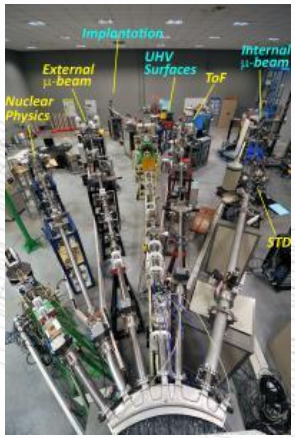
The phoswich solution

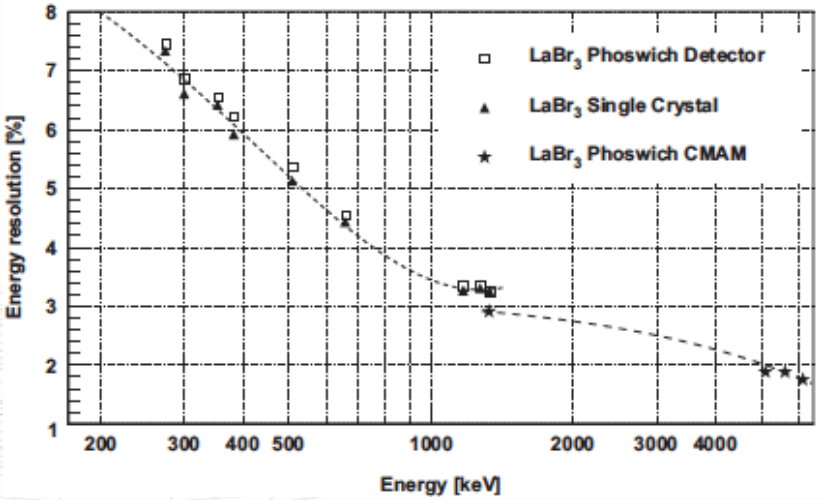
- Test with high-energy γ-rays at CMAM and analog electronics





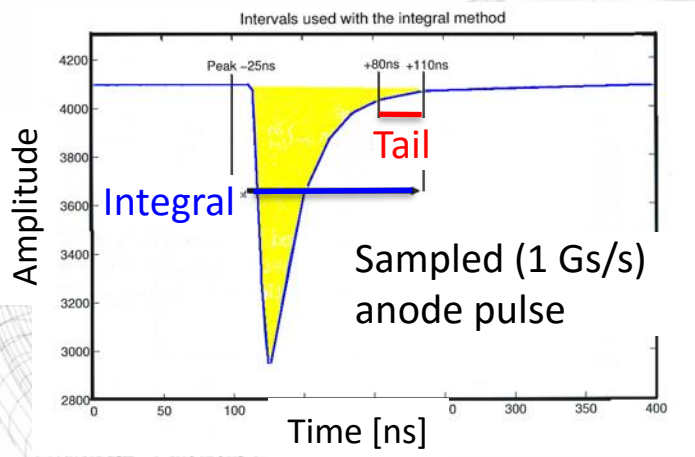
$^{19}F(p,\alpha\gamma)^{16}O$
[γ-rays at 6.1 MeV]

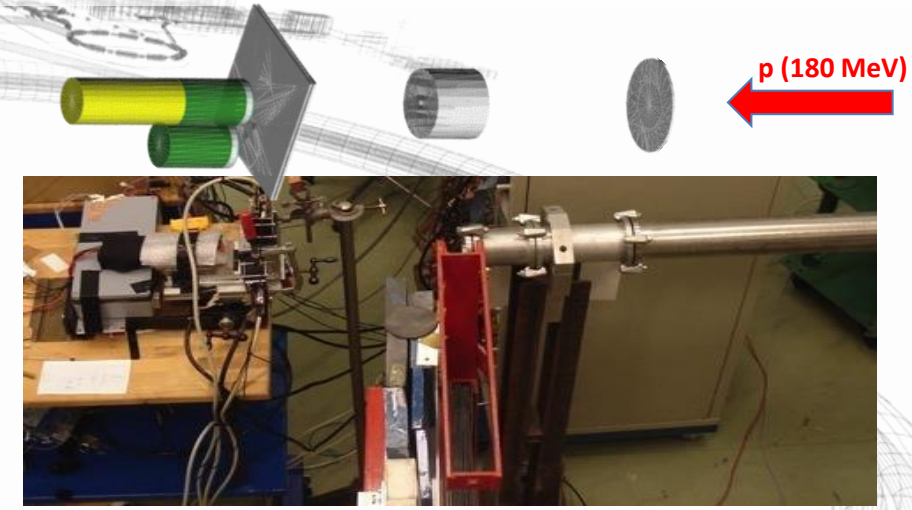




The phoswich solution

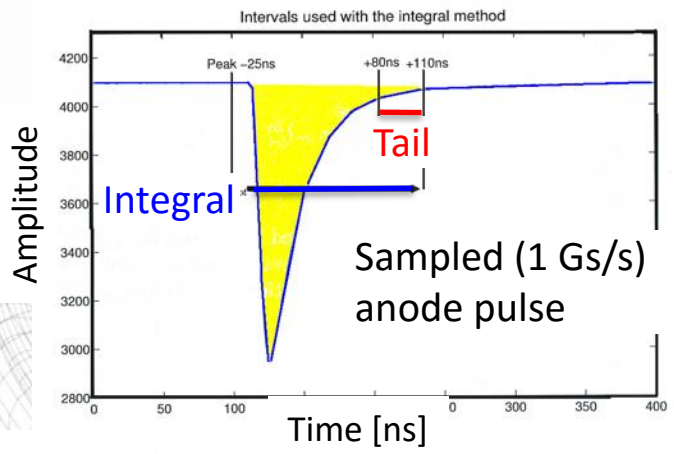
- Test with high-energy protons at TSL and digital electronics

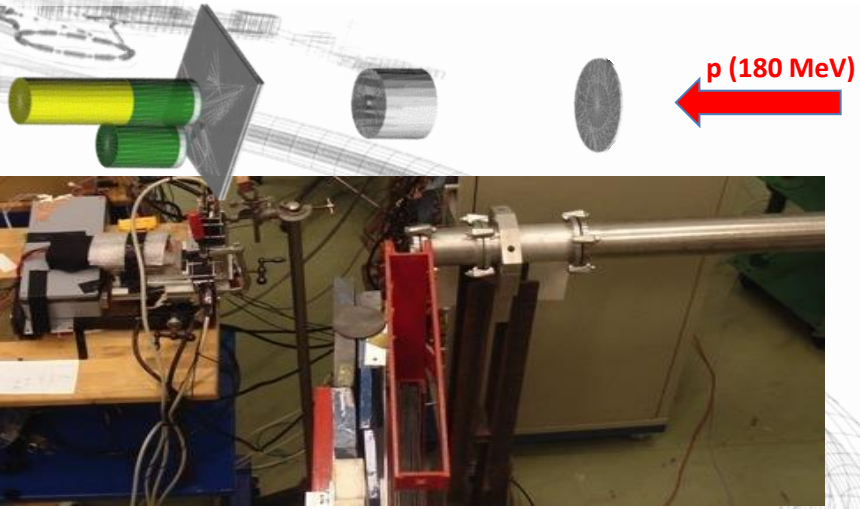


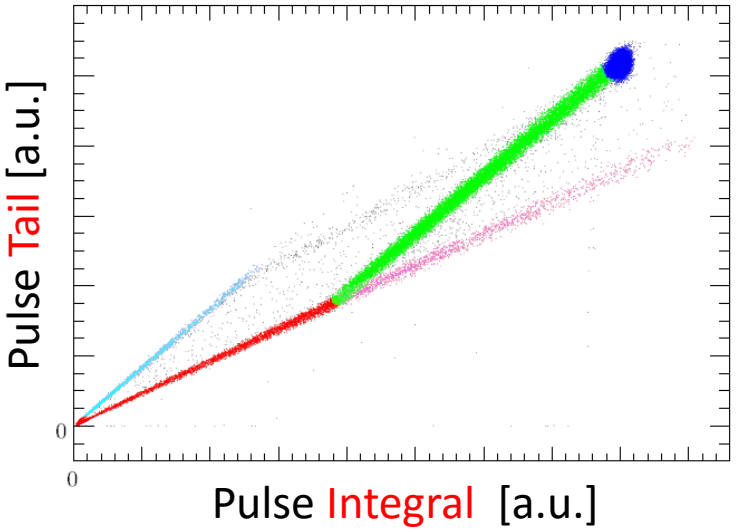


The phoswich solution

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



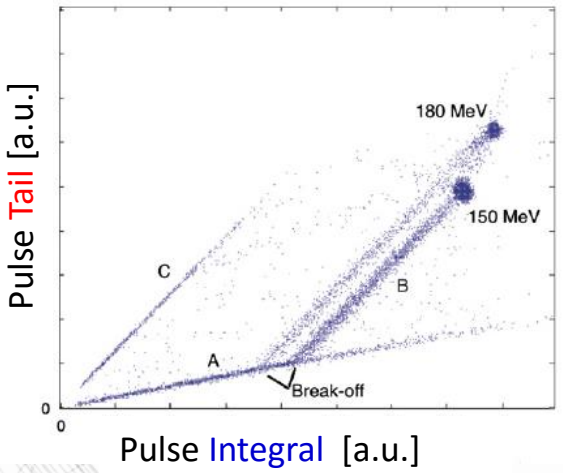




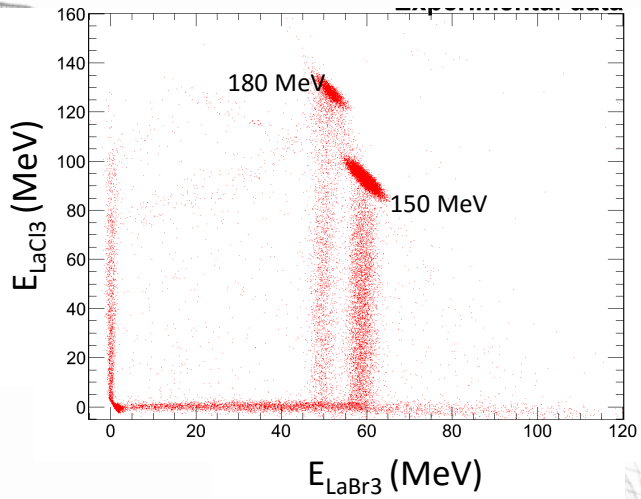
- Proton slowed down in the two xstals and stopped in the 2nd one (LaCl3)
- Proton slowed down in the two xtals and escaped from the 2nd xtal (or n knock-out)
- Proton slowed down in the 1st xtal and escaped from it
- Proton slowed dowd and stopped in 1st crystal (or p knock-out)
- Proton entered from the side to 2nd crystal

The phoswich solution

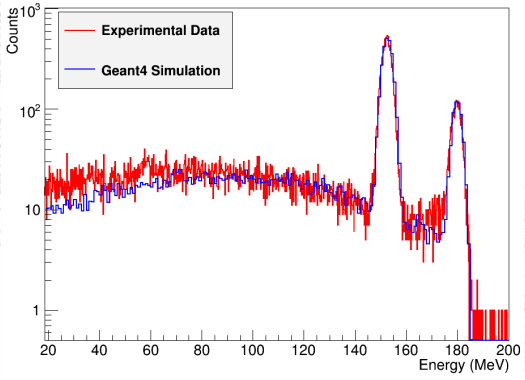
- Test with high-energy protons at TSL and digital electronics

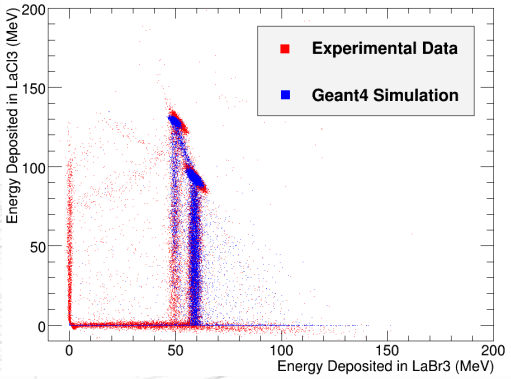


$$\begin{cases} I_{Br}^{total} = \dfrac{I^{tail} - a_{Cl} \cdot I^{total}}{a_{Br} - a_{Cl}} \\ I_{Cl}^{total} = \dfrac{a_{Br} \cdot I^{total} - I^{tail}}{a_{Br} - a_{Cl}} \end{cases}$$



- Geant4 simulations:

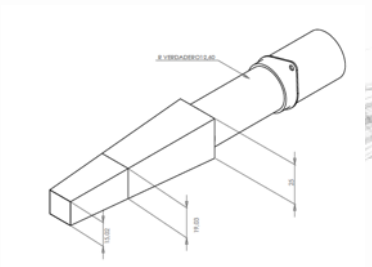


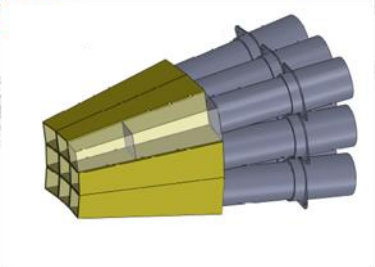


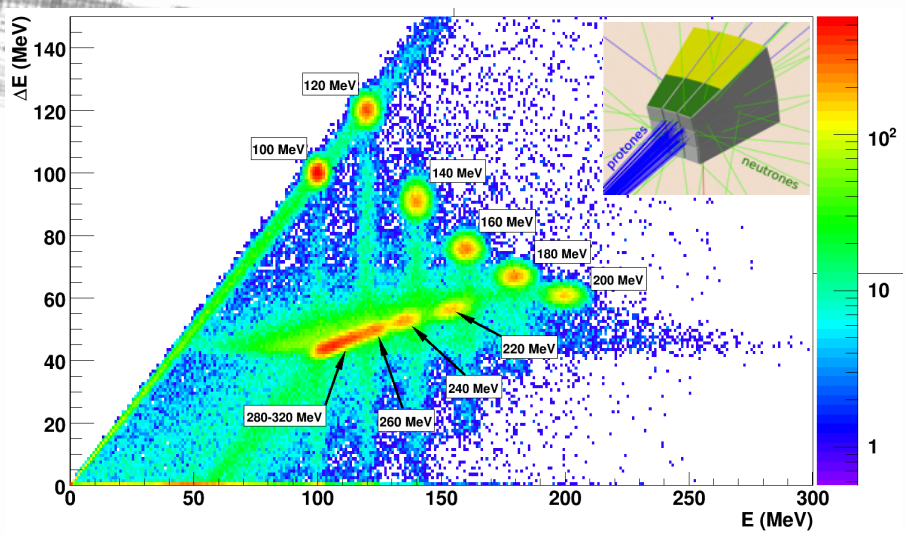
O. Tengblad, T. Nilsson, E. Nacher et al., NIM A 704 (2013) 19

CEPA4: a bigger phoswich array

- What we wanted…

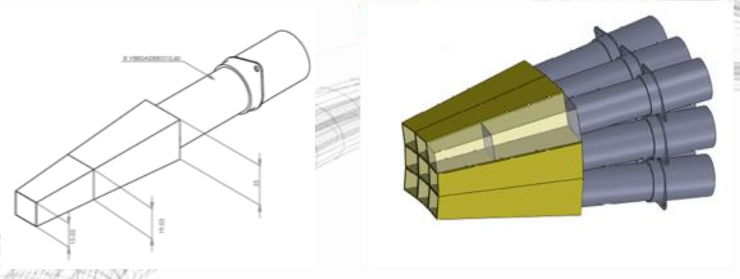


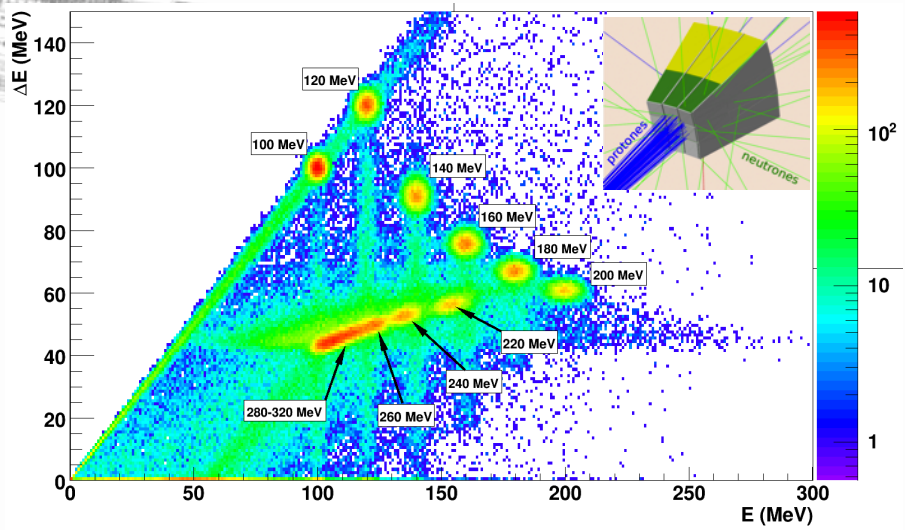




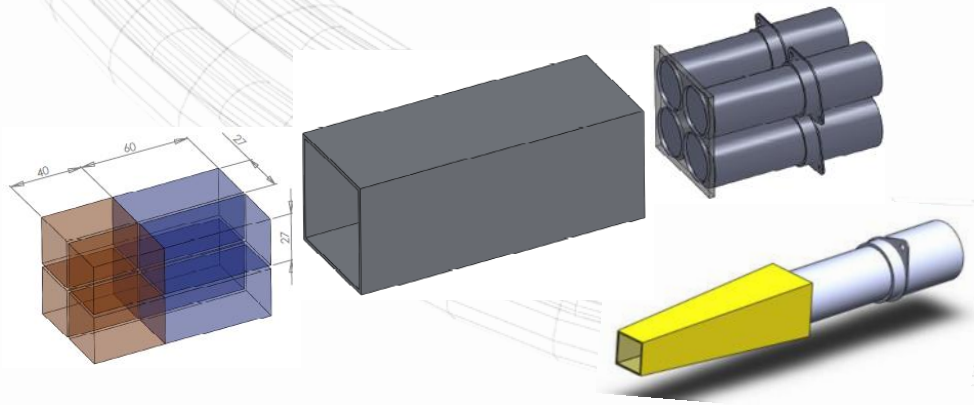
CEPA4: a bigger phoswich array

- What we wanted…





- What we got… CEPA4



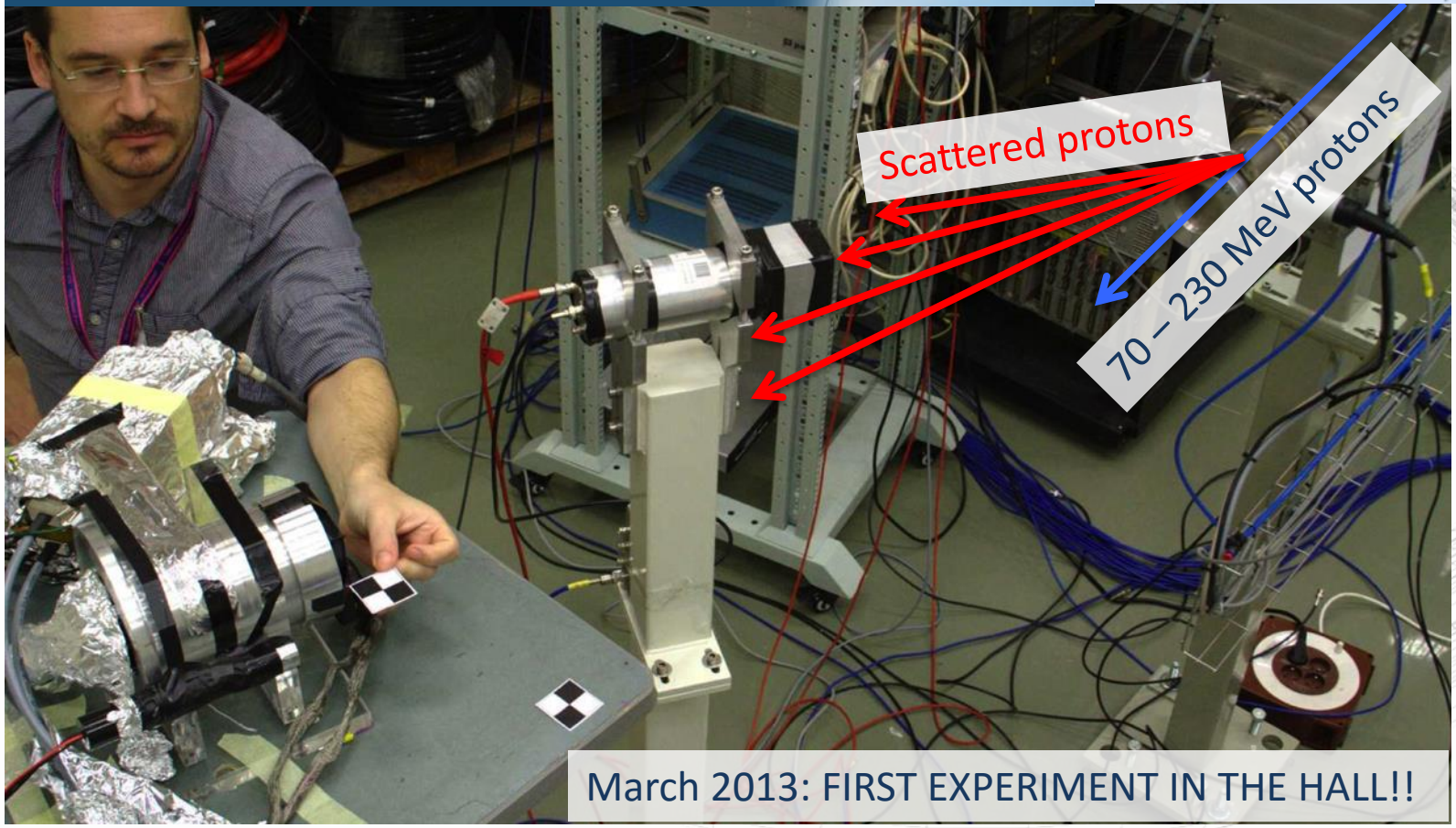
- 4 phoswich units in an Al (0.5mm) can
- $LaBr_3$ (4 cm) + $LaCl_3$ (6 cm) and 27 x 27 mm^2 entrance window
- No Al between the crystals, just 1 mm of Teflon (waterproof?)
- Test the optical insulation and the addback procedure

CEPA4: response to protons

Centrum Cyklotronowe Bronowice

ERA-NET for Nuclear Physics Infrastructures

GANAS

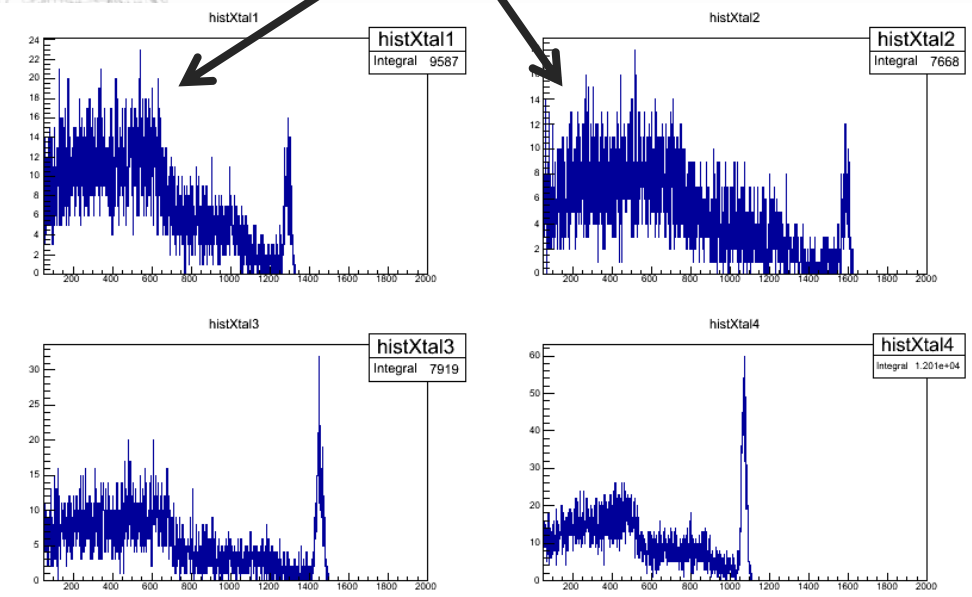


March 2013: FIRST EXPERIMENT IN THE HALL!!

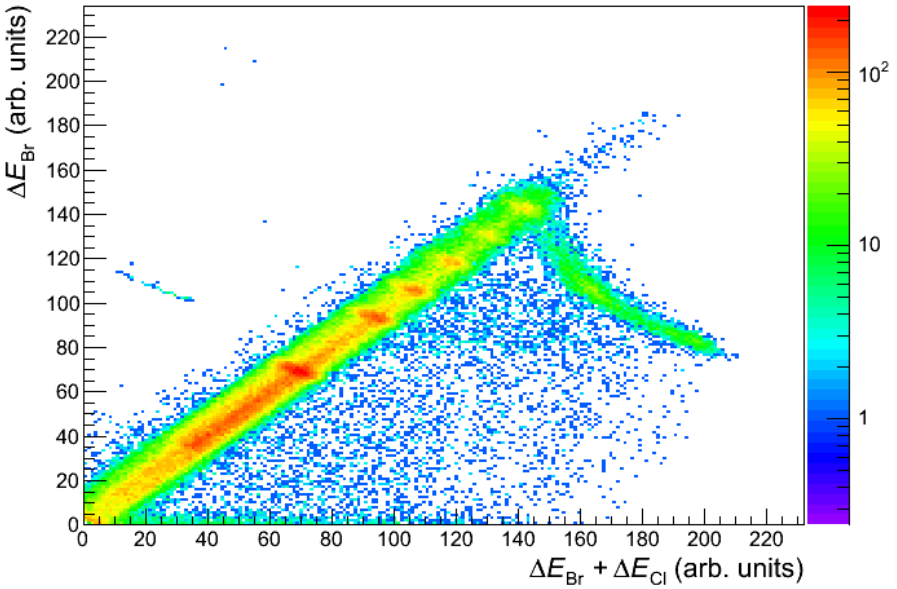
CEPA4: response to protons

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

Two crystals received many more protons scattered at the neighbouring setup

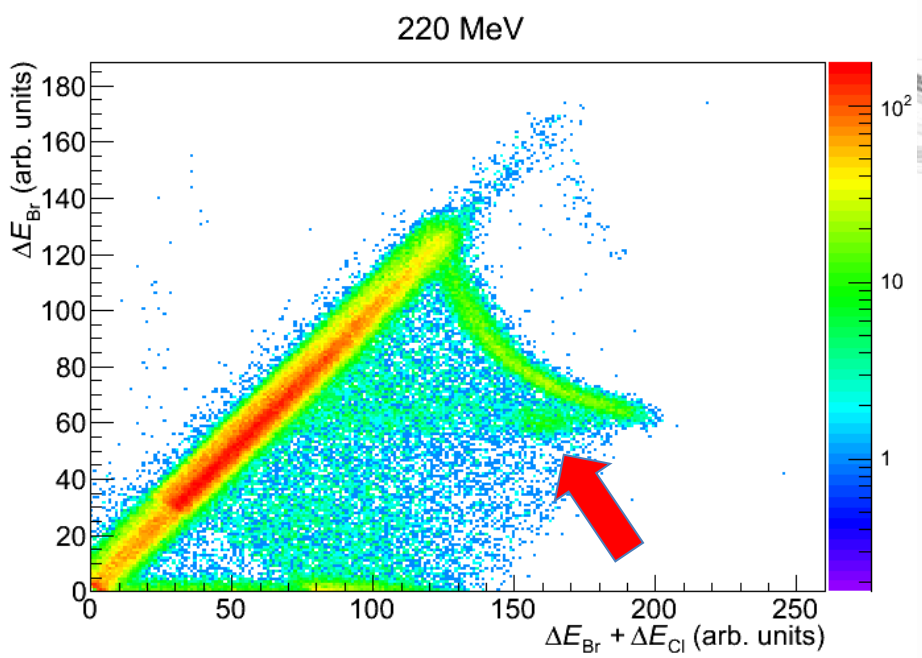


70, 90, 100, 110, 120, 130, 150, and 180 MeV



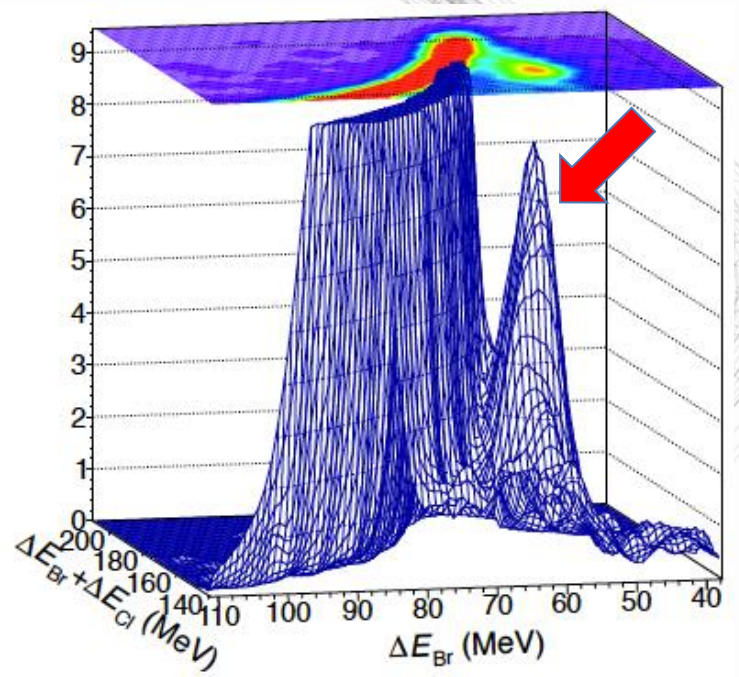
$$\begin{cases} I_{Br}^{total} = \dfrac{I^{tail} - a_{Cl} \cdot I^{total}}{a_{Br} - a_{Cl}} \\ I_{Cl}^{total} = \dfrac{a_{Br} \cdot I^{total} - I^{tail}}{a_{Br} - a_{Cl}} \end{cases}$$

CEPA4: response to protons



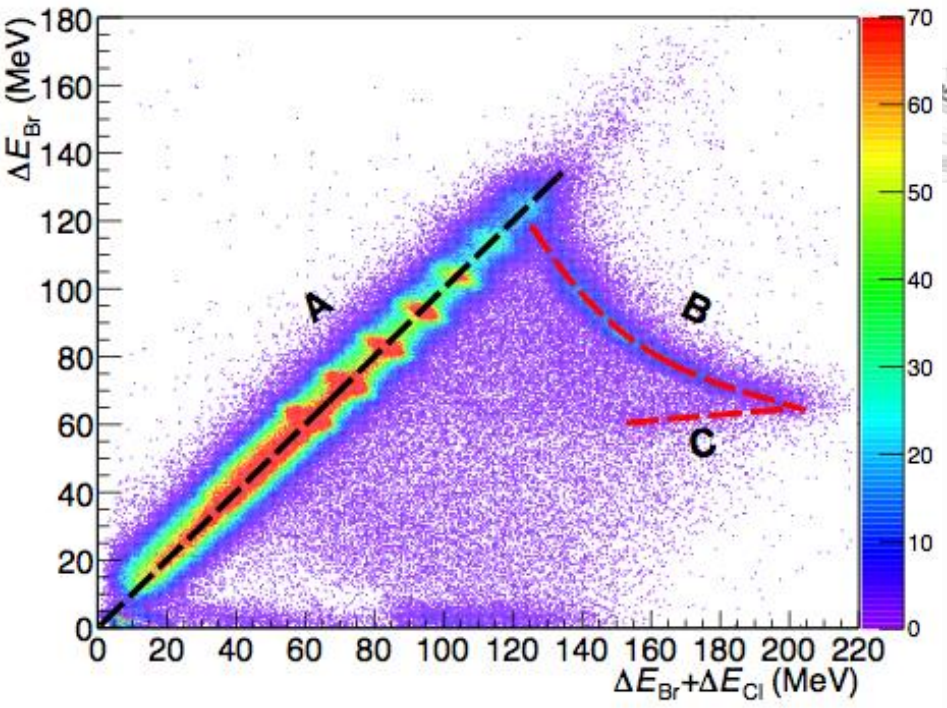
E_{LaBr3} vs E_{tot}

Energy above punch through measured for the first time!!



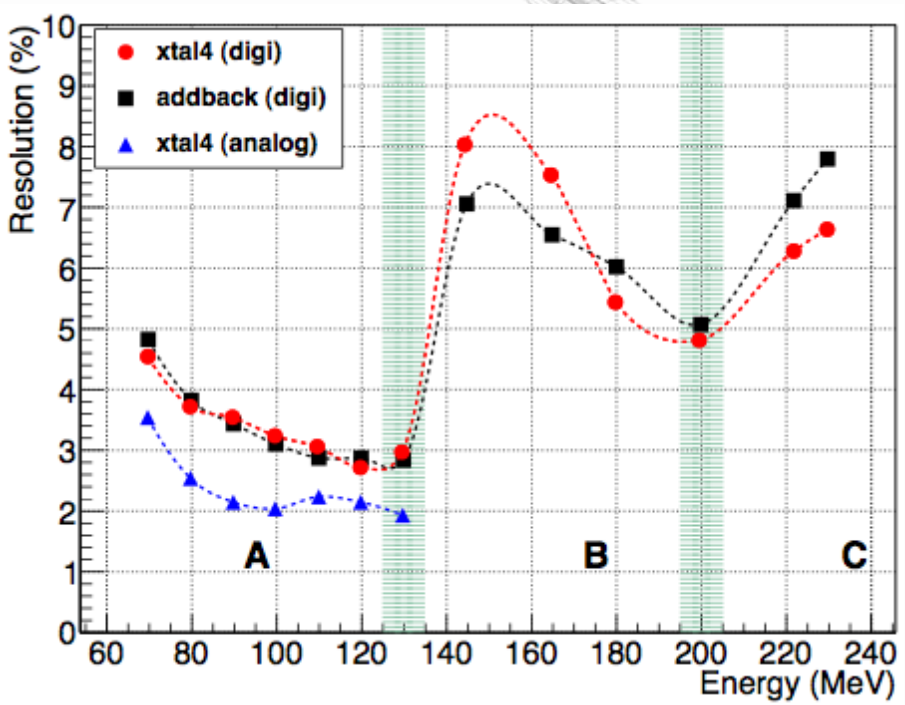
E. Nácher, M. Mårtensson et al., NIM A 769 (2015) 105

CEPA4: response to protons



Calibration: projection on lines B & C

- response beyond 200 MeV
- energy resolution

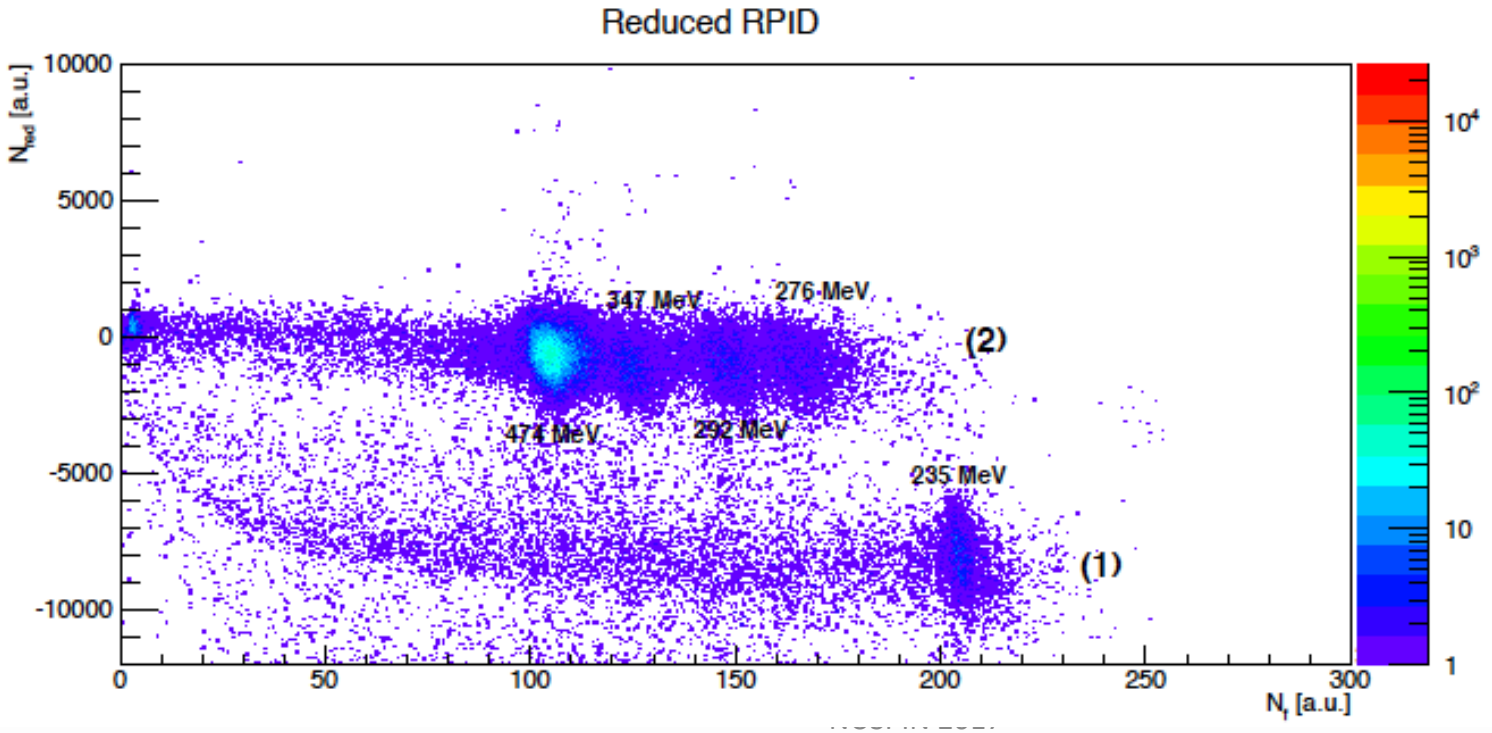


E. Nácher, M. Mårtensson et al., NIM A 769 (2015) 105

The iPhos concept

- CsI(Tl) -> 2 different scintillating states with τ_f = 0.6 µs and τ_s = 3.25 µs
- Ratio of light output from the 2 components depends on the ionization density

- One can perform PID or even distinguish if the particle was stopped or punched through



Summary & Conclusions

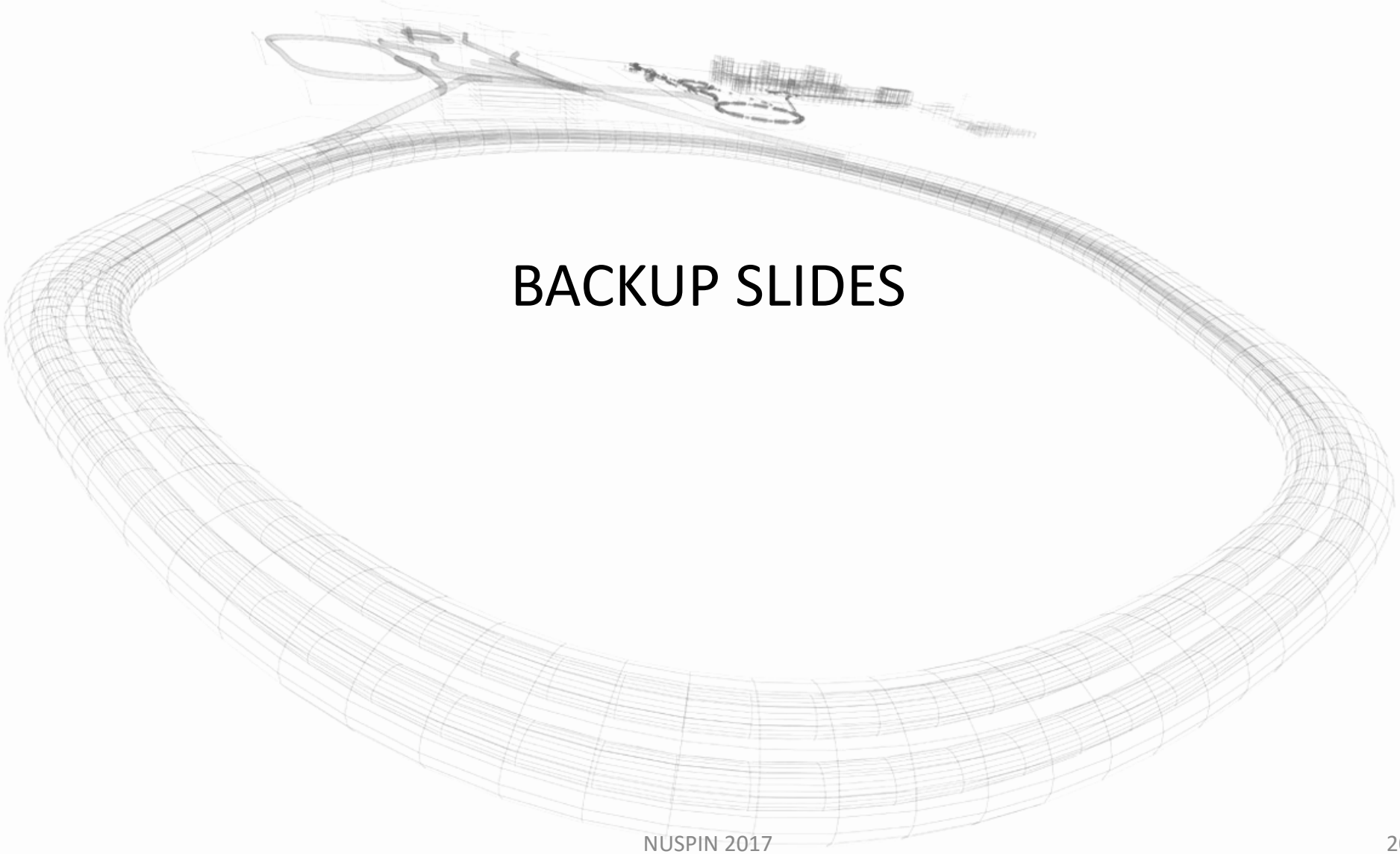
1 – We have a new high-resolution phoswich array: CEPA4. Good optical insulation and moisture-proof so far, even with no Aluminum casing for the individual crystals.

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

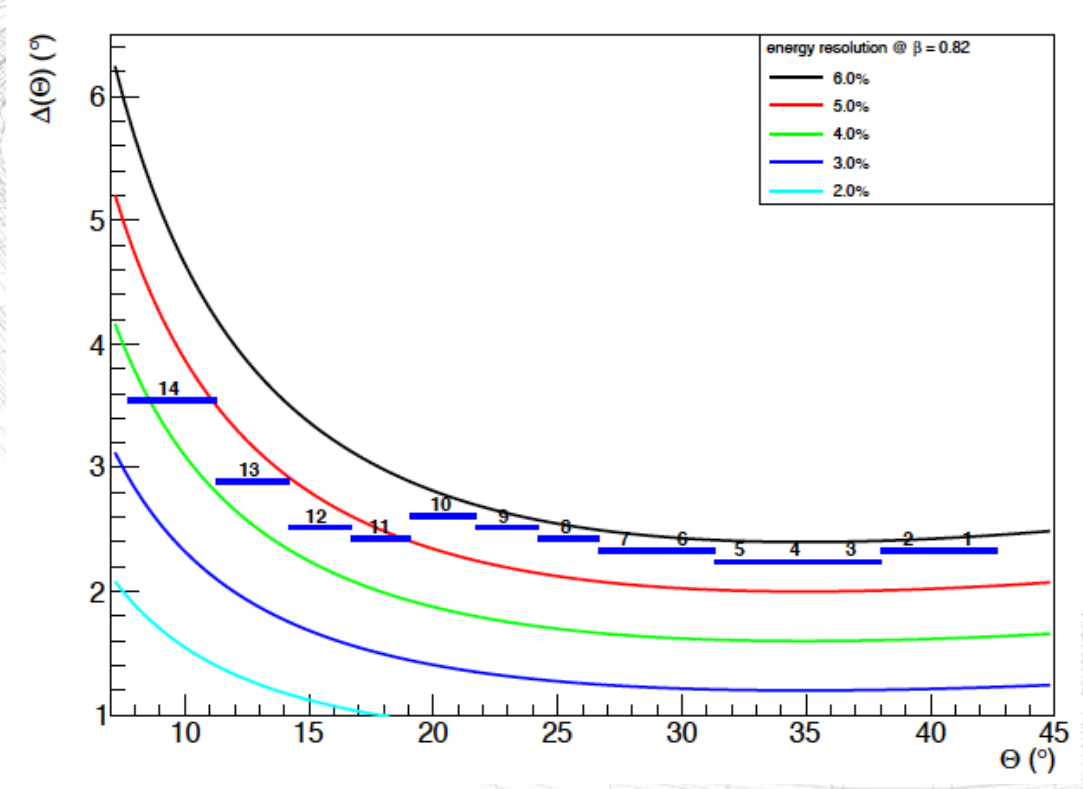
3 – The PSA procedure has been tested and has provided good results even beyond the total punch-through energy. We have a reliable method to calibrate the detector by regions.

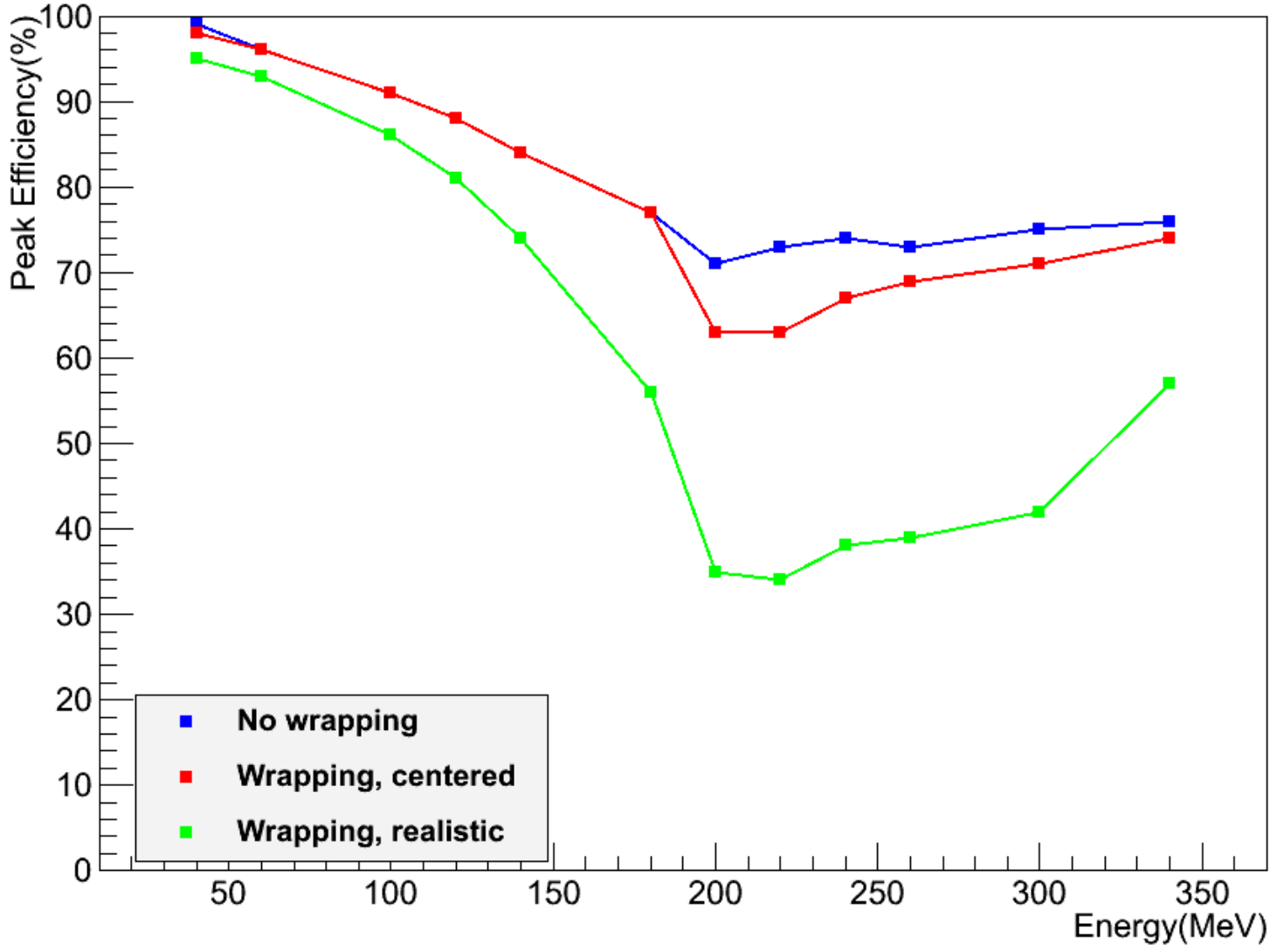
5 – The energy resolution is good up to the total punch-through and still acceptable at 230 MeV

4 – iPhos concept up and working...



BACKUP SLIDES


energy resolution @ β = 0.82
6.0%
5.0%
4.0%
3.0%
2.0%
Δ(Θ) (°)
Θ (°)
14
13
12
11
10
9
8
7
6
5
4
3
2
1


Peak Efficiency(%)
100
90
80
70
60
50
40
30
20
10
0
50
100
150
200
250
300
350
Energy(MeV)
No wrapping
Wrapping, centered
Wrapping, realistic

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

$$\begin{cases} I_{Br}^{tail} = a_{Br} \cdot I_{Br}^{total} \\ I_{Cl}^{tail} = a_{Cl} \cdot I_{Cl}^{total} \end{cases} \quad (1)$$

$$\begin{cases} I^{total} = I_{Br}^{total} + I_{Cl}^{total} \\ I^{tail} = I_{Br}^{tail} + I_{Cl}^{tail} \end{cases} \quad (2)$$

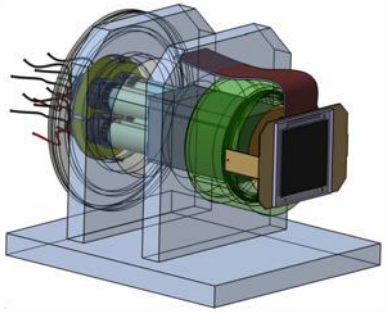
$$\begin{cases} I_{Br}^{total} = \dfrac{I^{tail} - a_{Cl} \cdot I^{total}}{a_{Br} - a_{Cl}} \\ I_{Cl}^{total} = \dfrac{a_{Br} \cdot I^{total} - I^{tail}}{a_{Br} - a_{Cl}} \end{cases} \quad (3)$$

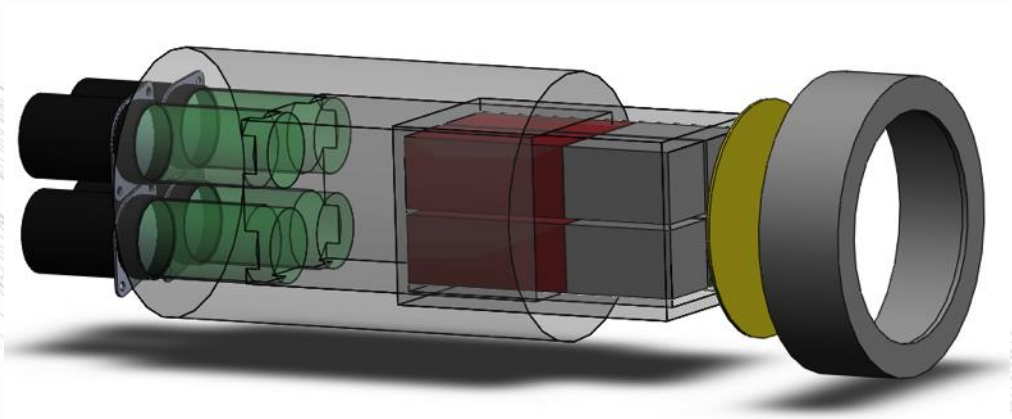
CEPA4: a bigger phoswich array

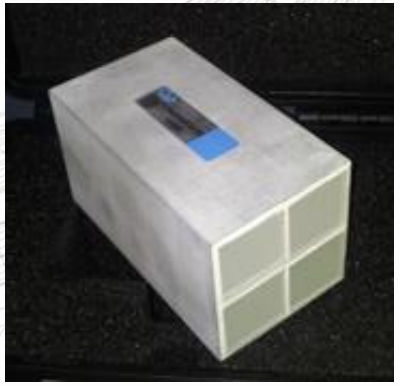
- Readout: 4 Hamamatsu 8-stage PM Tubes R5380
  (recently changed to R7600U-200: shorter & square-shaped)

- 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.







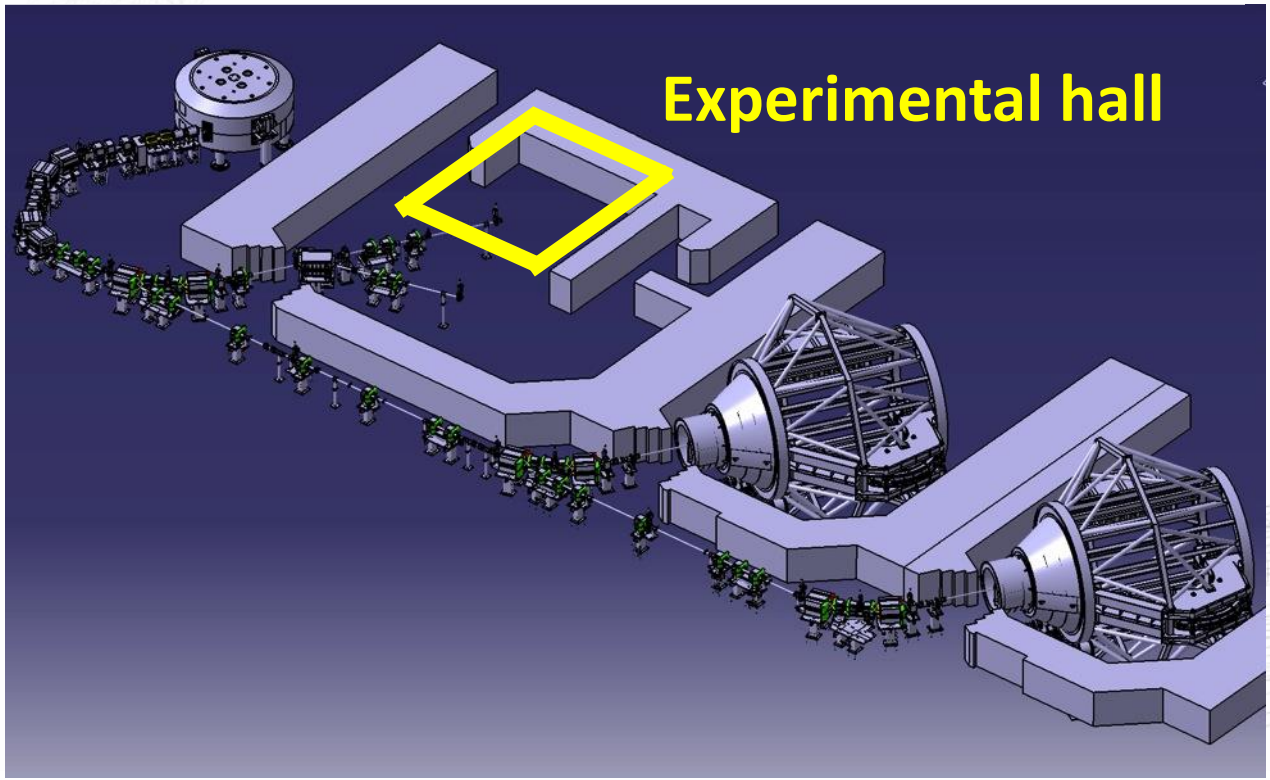
CEPA4: response to protons

Centrum Cyklotronowe Bronowice

ERA-NET for Nuclear Physics Infrastructures

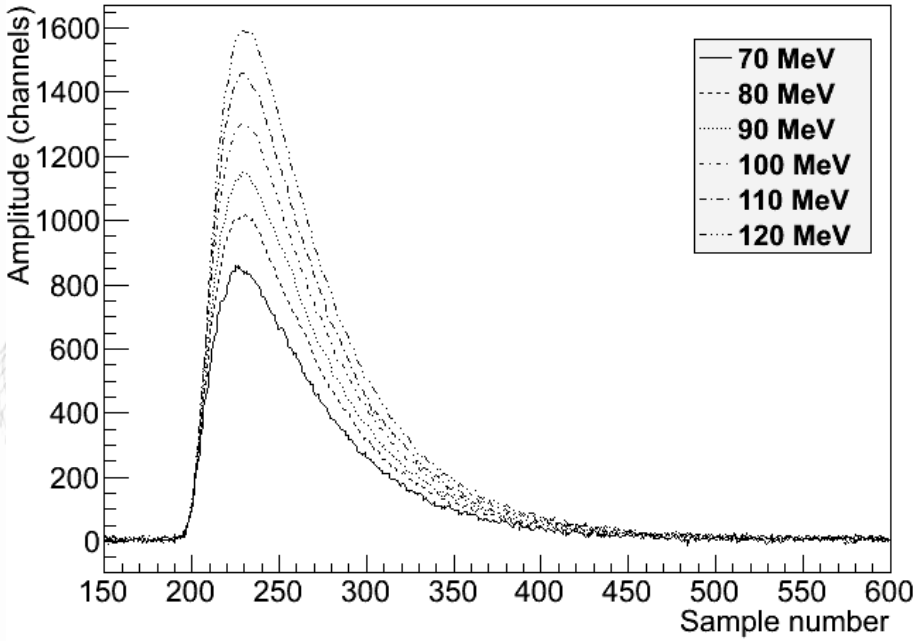
GANAS

- Newly constructed cyclotron (IBA Proteus C-235).
- Proton beam energies within 70-230 MeV ($\Delta E \sim 0.7\%$)
- Mainly for cancer therapy and medical applications, but…



Many thanks to A. Maj, B. Szpak, et al. for the great support!!

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