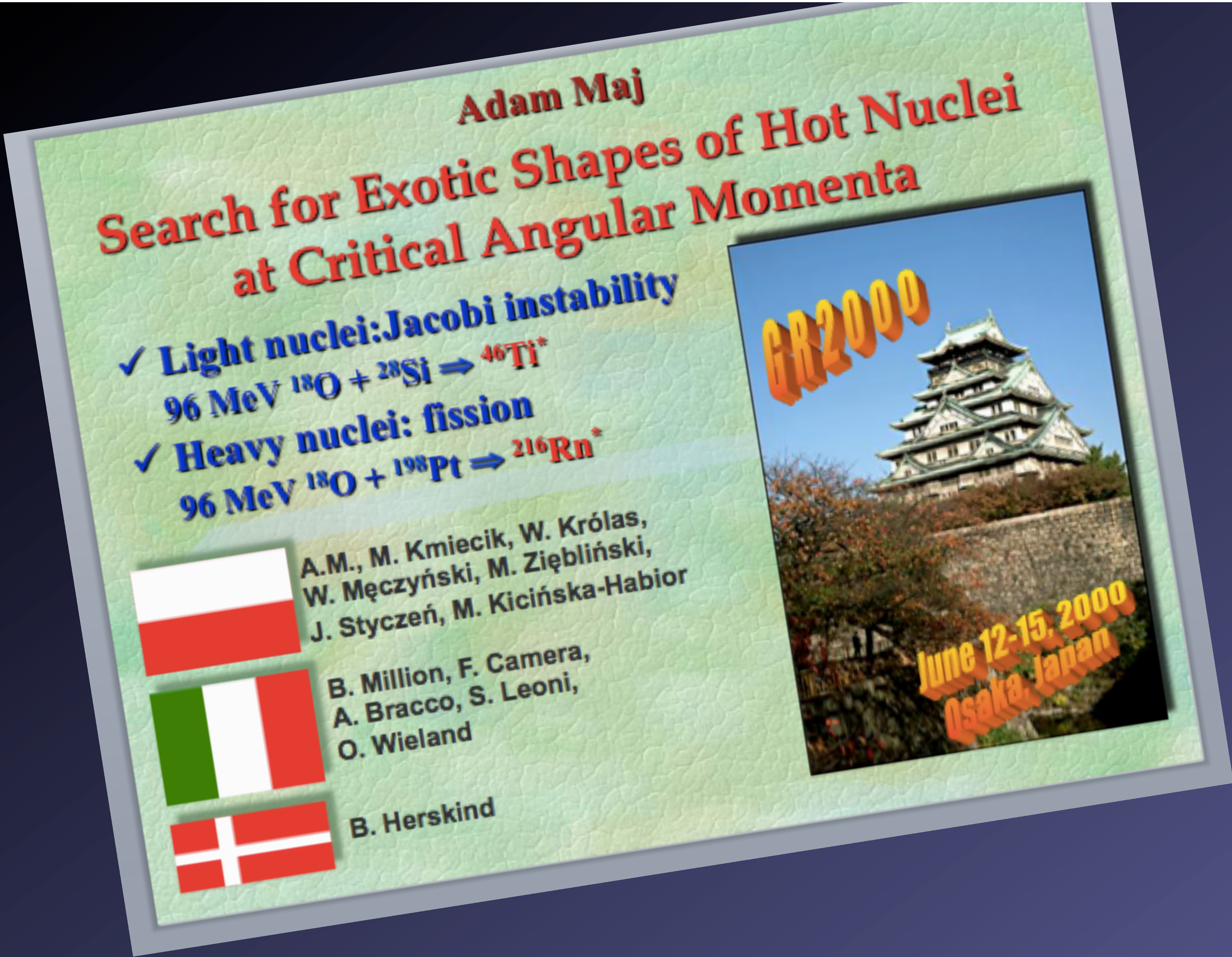
Adam Maj
IFJ PAN Krakow

Nuclear physics research at the proton therapy facility CCB in Krakow

HST15 INTERNATIONAL SYMPOSIUM ON HIGH-RESOLUTION SPECTROSCOPY & TENSOR INTERACTIONS

Osaka, November 16-19, 2015

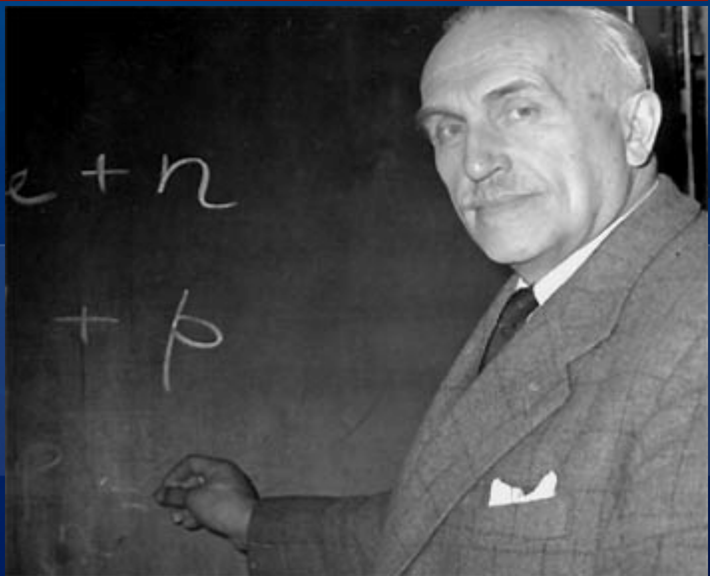


My first visit to Osaka (and Japan): June 2000

Introduction

The Henryk Niewodniczański Institute of Nuclear Physics
Polish Academy of Sciences

IFJ PAN in Kraków was established in 1955, thanks to Prof. Henryk Niewodniczański, who was the 1st director (until his death in1968). Prof. Niewodniczański was post-doc of Ernest Rutherford.



Since 2003 IFJ PAN belongs to Polish Academy of Sciences (PAN)

The Henryk Niewodniczański Institute of Nuclear Physics
Polish Academy of Sciences

Particle physics and astrophysics

Nuclear and strong interactions physics

Condensed matter physics

Interdisciplinary and applied research

Theoretical physics

Main Research Fields

- ca. 500 personnel
- Prof. 50, Assoc. Prof. 40, Ph.D. 150
- PhD studies – ca. 90 students
- 6 divisions: 27 departments
- centres of excellence
- centres of advanced technology
- 4 accredited laboratories
- Equipment and Scientific Infrastructure Construction Division

General information

Since 2012 eye cancer (melanoma) protontherapy is conducted in IFJ PAN using home made 60 MeV proton cyclotron AIC-144. So far 120 patients were treated.

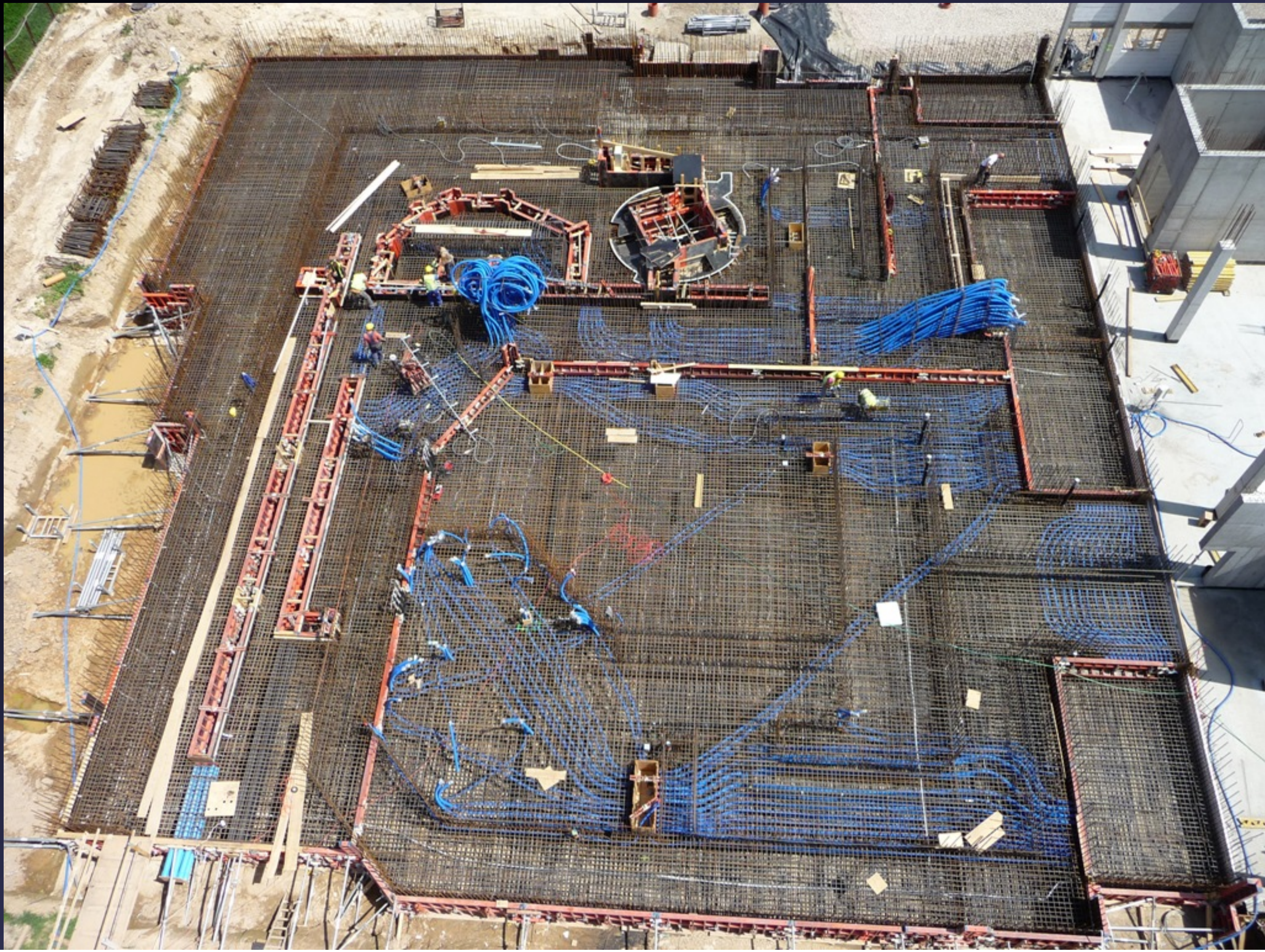
In December 2012, a new proton cyclotron became operational at the Institute of Nuclear Physics PAN in Kraków. Together with the existing cyclotron AIC-144, it is a part of the Cyclotron Center of Bronowice (CCB).

Although the primary objective of the facility is proton cancer therapy, an extensive research program at this cyclotron is planned in the field of nuclear physics, radiobiology, dosimetry and medical physics.


3.03 2011 Just before the start …..


April 2011
SM LOGISTIC
ZEPPELIN
Marek Jeżabek
Adam Maj
Magdalena Zydek
Paweł Olko
2011/03/31

Autumn 2011



May 2012

Installation of the Proteus C-235 cyclotron

11 May 2012

Instalation of IBA Proteus C-235 cyclotron

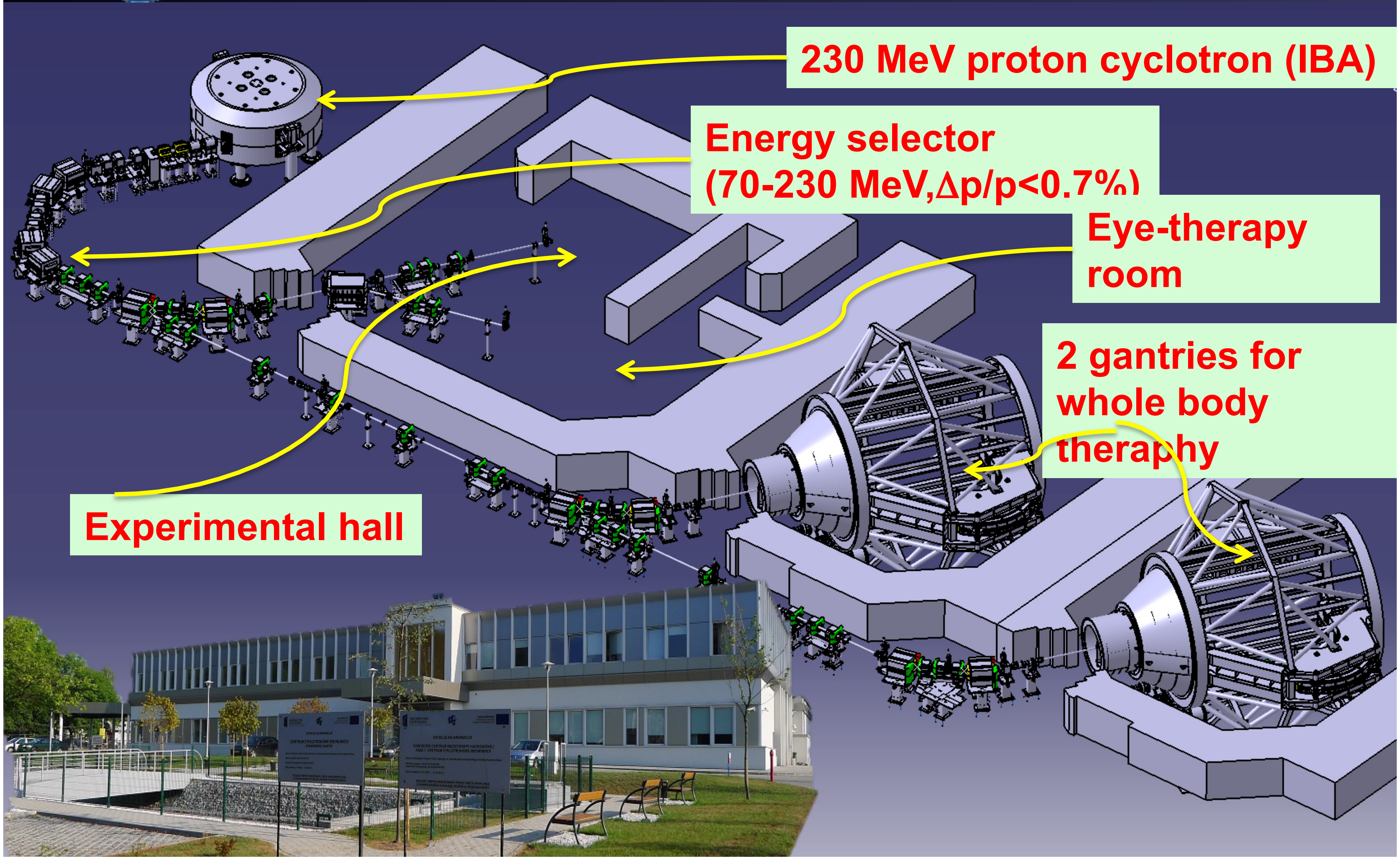

11 May 2012
Krakow – Proton Therapy Center

Spring 2013

Autumn 2013


September 2014

Cyclotron Center Bronowice
Institute of Nuclear Physics Polish Academy of Sciences
Krakow, Poland



Proteus C-235 cyclotron

Ion Beam Applications S.A. (IBA), Louvain-la-Neuve, Belgium

cyclotron:	isochronic, 4-sectors, CW
particles	protons
ion source:	P.I.G with hot cathod
proton energy:	**230 MeV** (β = 0.596, γ = 1.245), constant
energy dispersion:	$\Delta E/E < 0.7\%$
beam intensity:	**600 nA (4 x 10^{12} p/s) – 0.1 nA (6 x 10^{8} p/s)**
emmitance	horizonthal - 11 π mm mrad,

diameter 434 cm
height: 210 cm

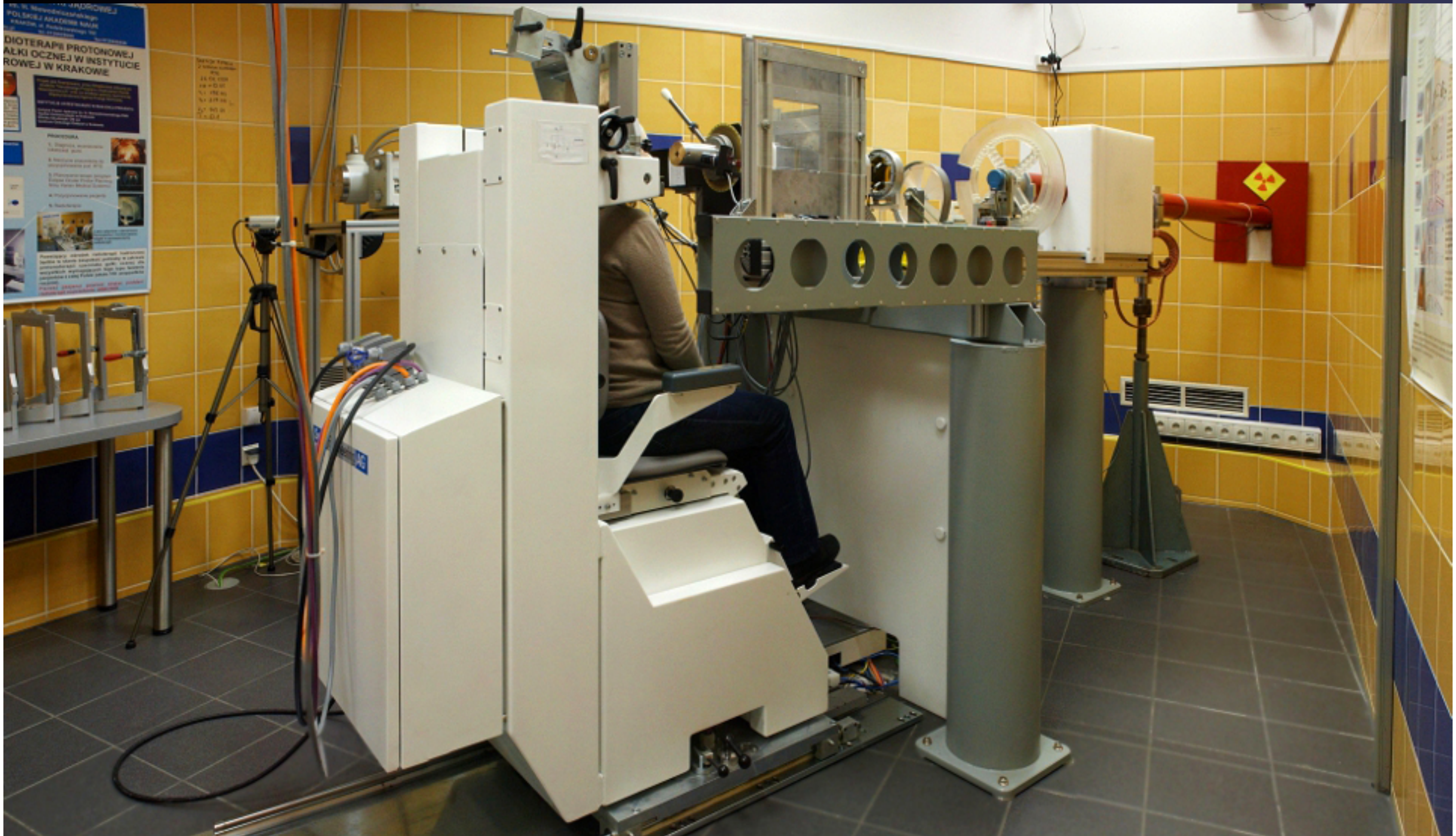
Energy selector

- energy range **70- 230 MeV**
- time to change energy **< 10 s**
- **dp/p < 0.7%**
- scanning beam

Timetable of CCB

- signing the contract	2.08.2010
- building permission	10.02.2011
- start of the construction	17.03.2011
- installation of the C-235 cyclotron	05.2012
- acceptance tests, physics exp. start	11.2012
- medical building	06.2013
- installation of gantry 1	07.2013
- gantry 1 in tested	06.2014
- gantry 2 in operation – end of the contract	09.2015

Total cost (buildings, cyclotron, eye therapy room, 2 gantries): 62 M€ (85%: EU, 15%: PL)

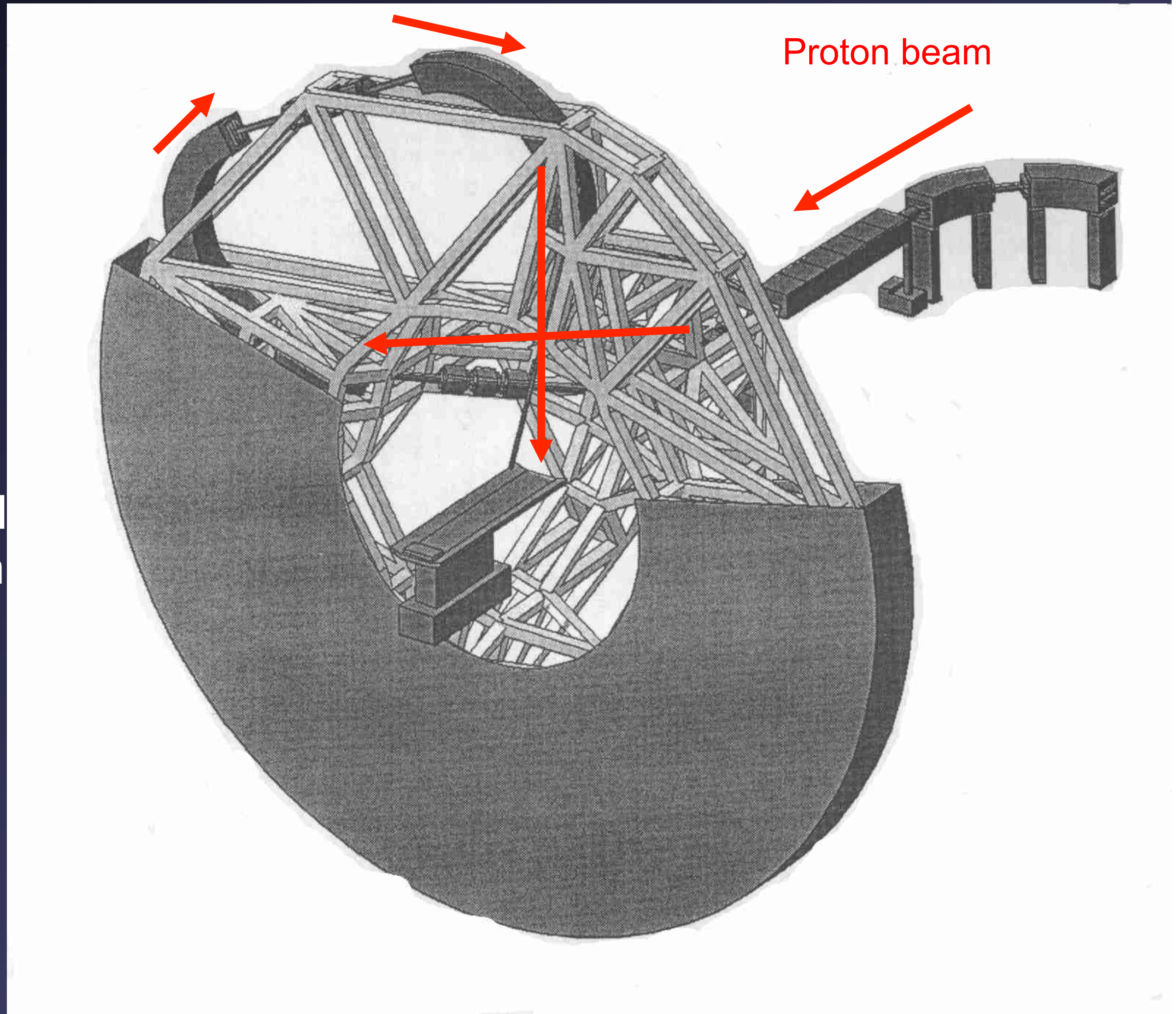


Gantry

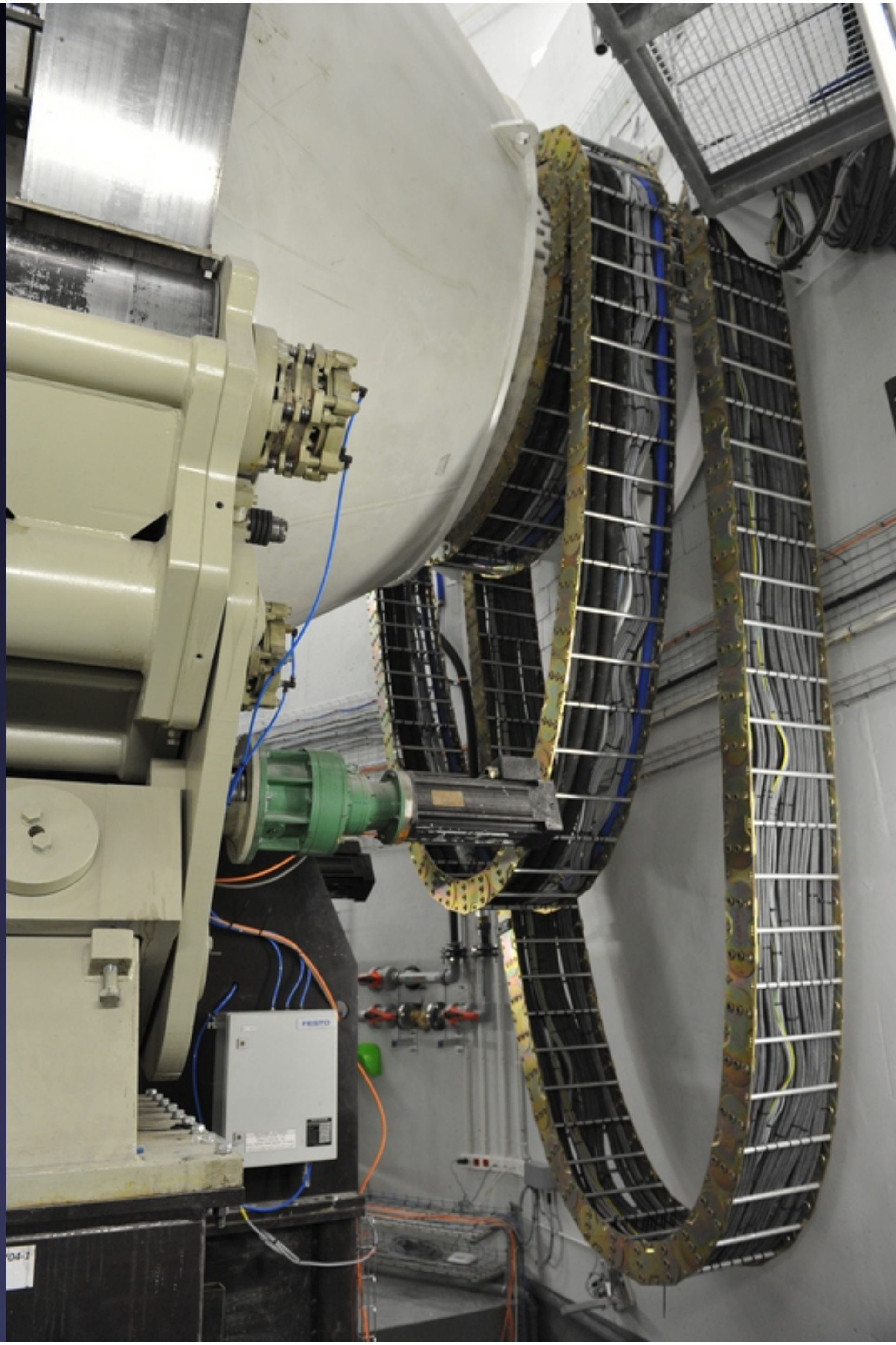
Gantry:
is a radiotherapy tool which allows to treat patients with protons from all directions

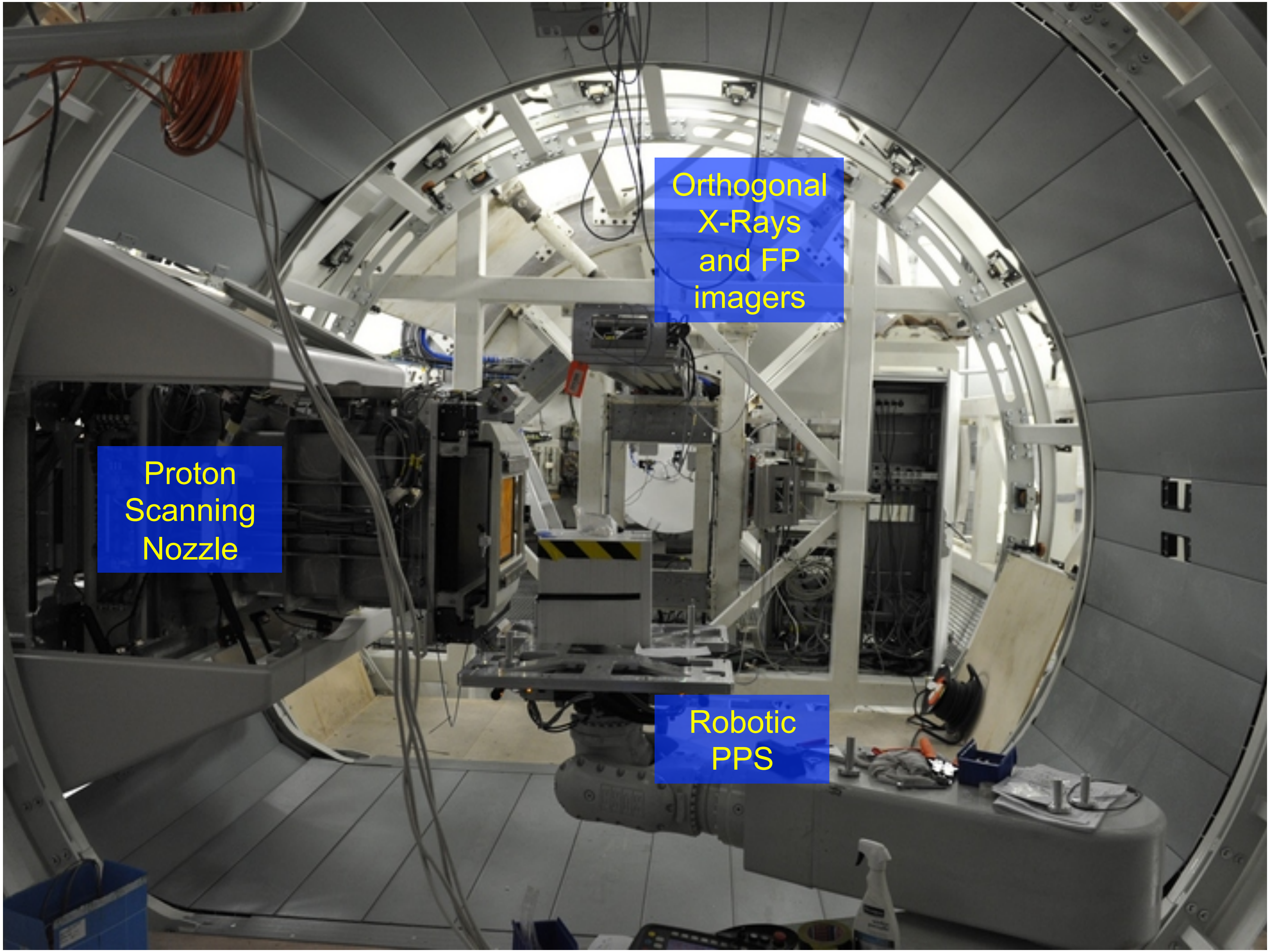
Problem:
The weight of the magnets more than 10 tons. Required precision of irradiation 1 mm

Solution:
Rotating construction, 100 tons, 11 m in diameter

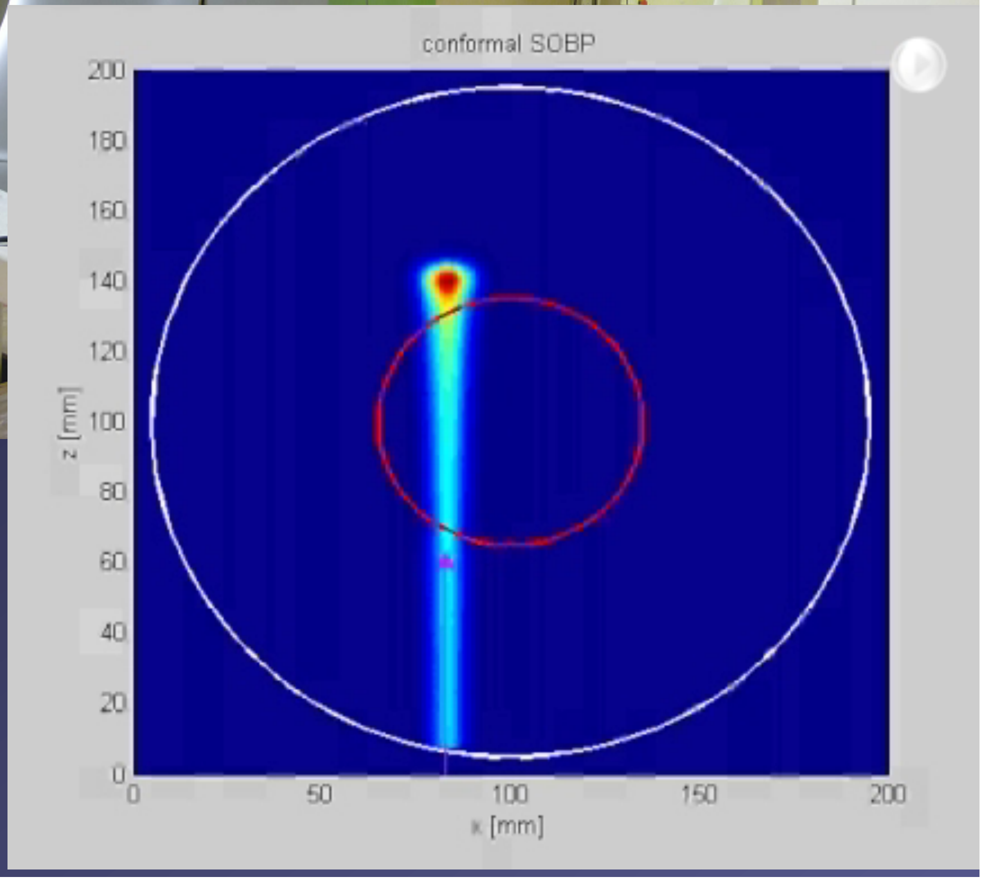


Gantry ready for transport




Orthogonal X-Rays and FP imagers
Proton Scanning Nozzle
Robotic PPS

Gantry with the scanning „pencil” beam



- 3 mm and 6 mm diameters available
- Intensity: dose of 2 Gy delivered to volume of 10 x 10 x10 cm3 in 60 s

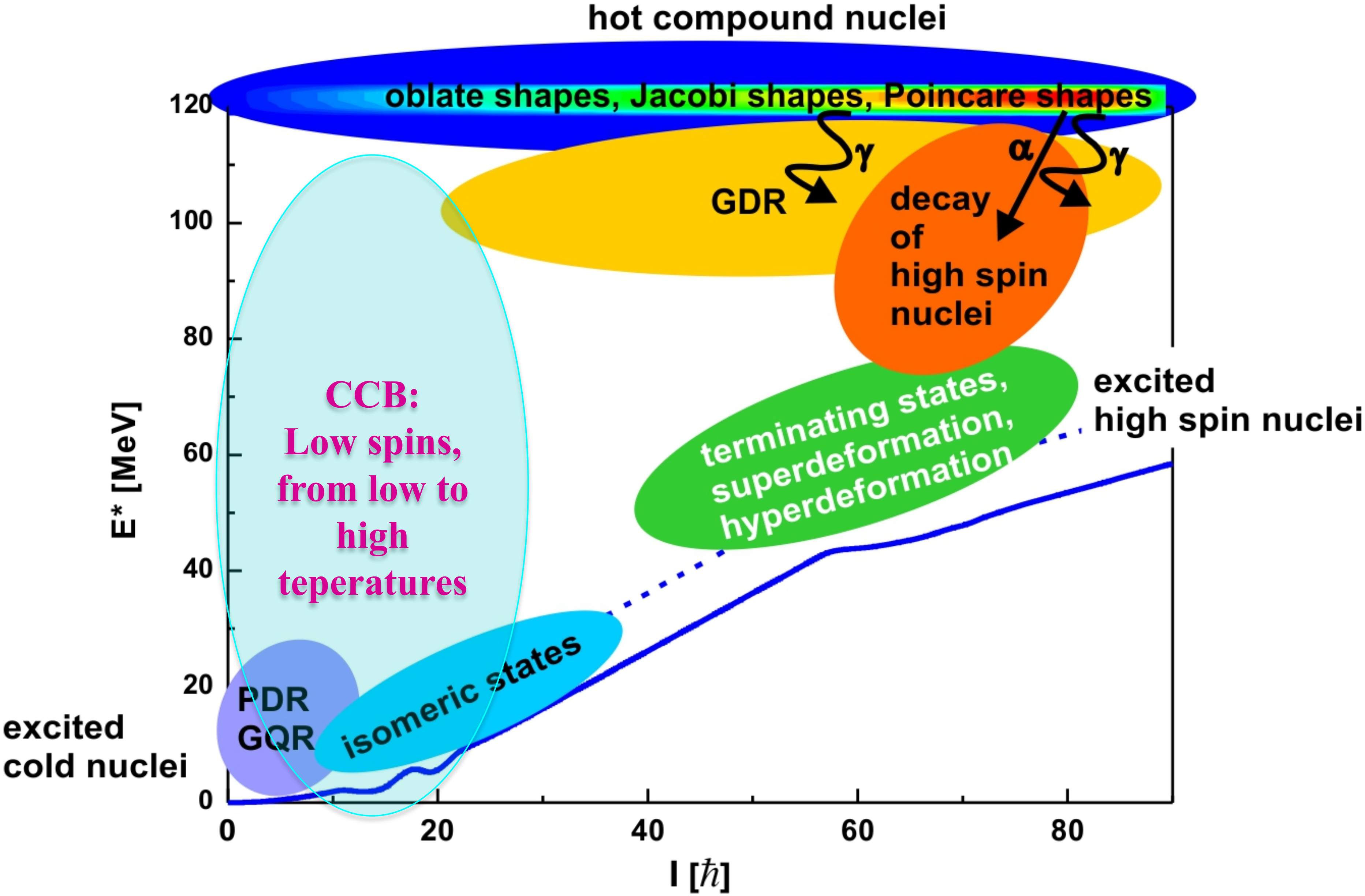
Gantry with the scanning beam

Main applications

Cancers of:
- Central Nervous System
- head and neck
- prostate
- children

Research at CBB: Areas of Interest and Instrumentation

Subjects of interest

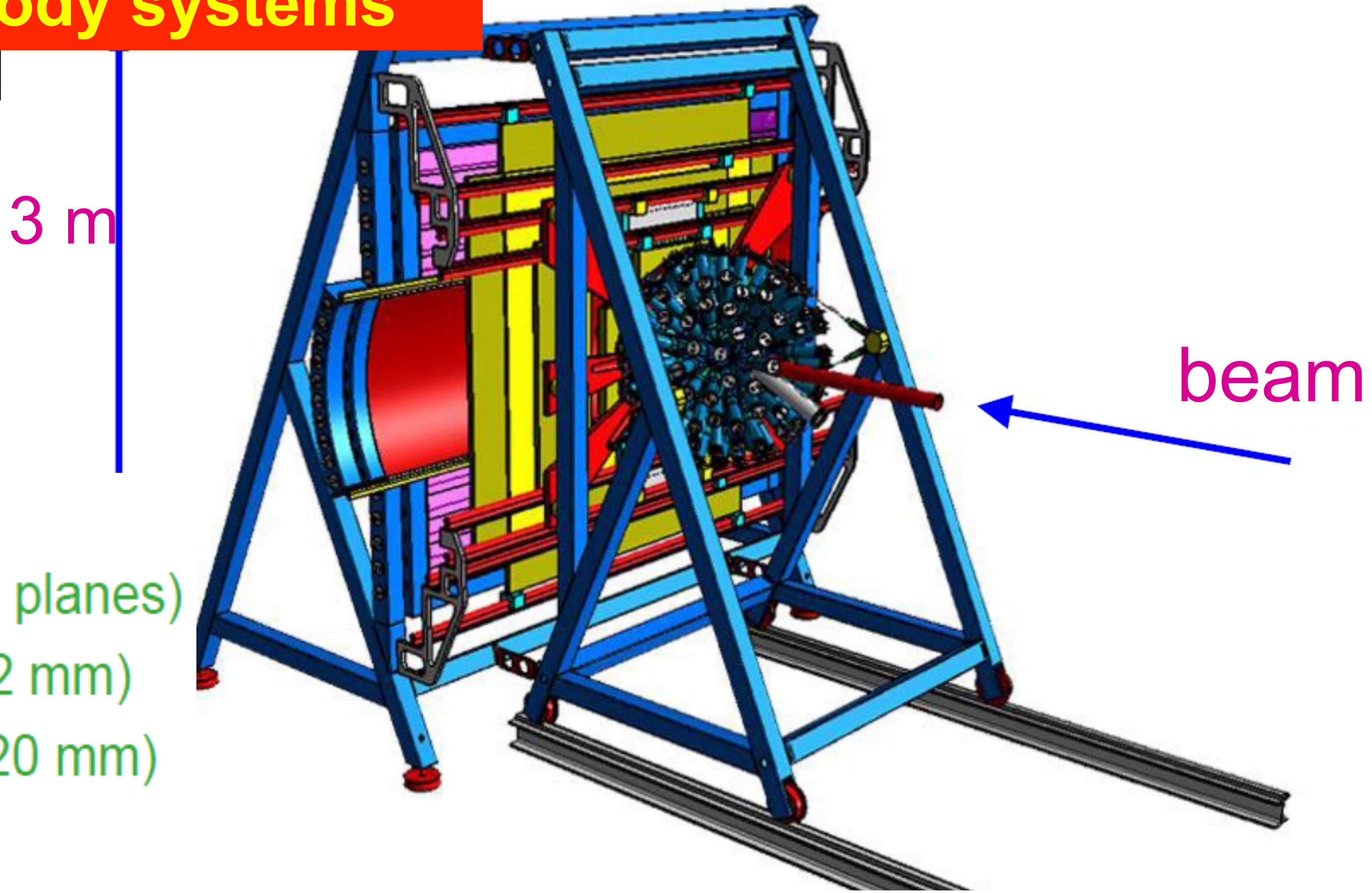


Beam at the target for the first time: February 21, 2013

1. BINA array (Big Instrument for Nuclear reaction Analysis)

To study the dynamics of few-body systems

Moved from KVI to Krakow



Wall:

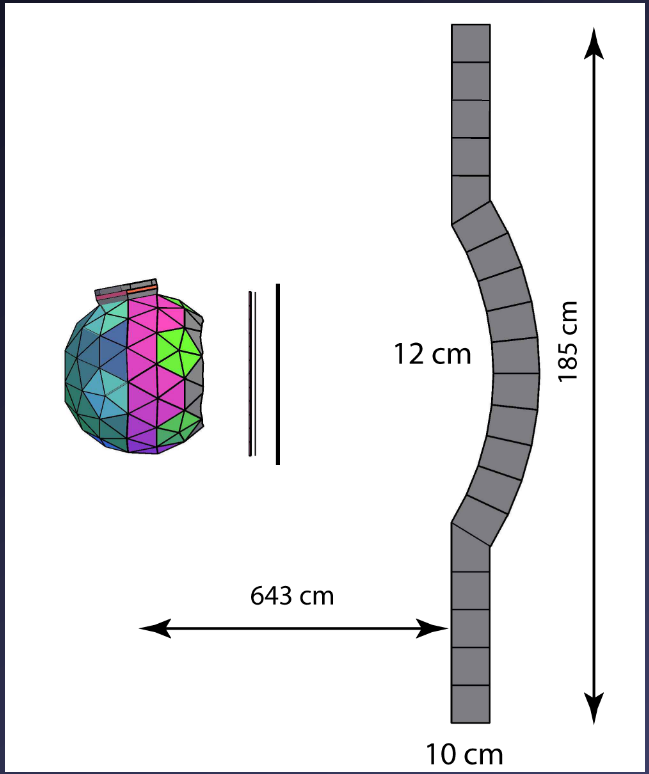
- MWPC (3 planes)
- ΔE (24 x 2 mm)
- E (20 x 120 mm)

Ball:

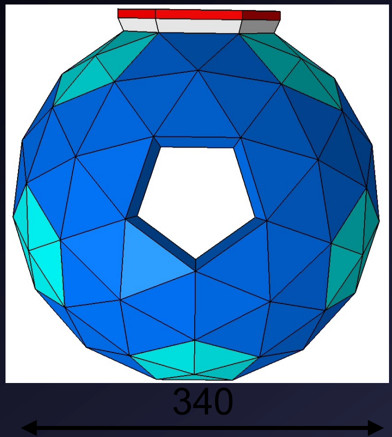
- Phoswich (149 x 90/30 mm)

BINA – E detector

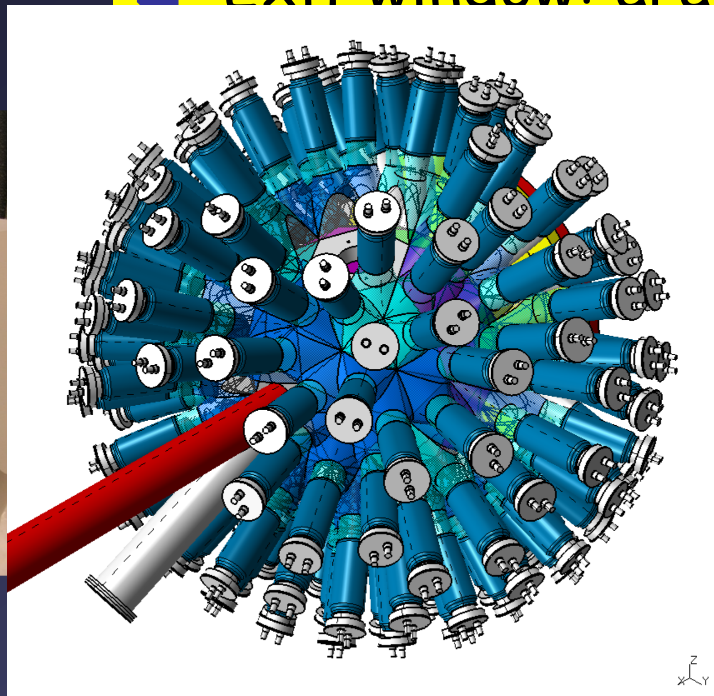
- 20 scintillator bars (BC-408),
- Central ten: 120 mm thick and 2200mm long, rest 100mm thick and 1800mm long.
- Two-side readout.

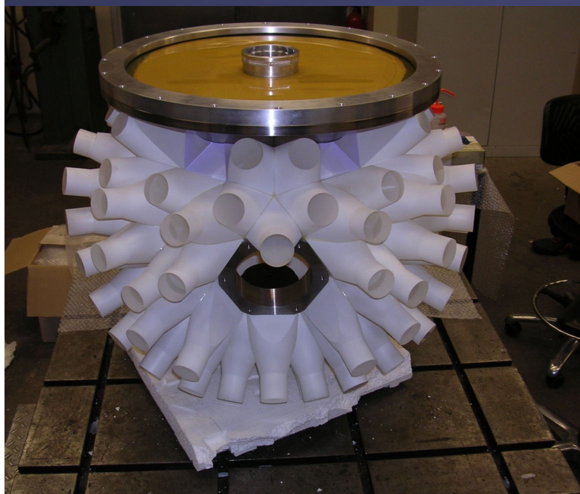


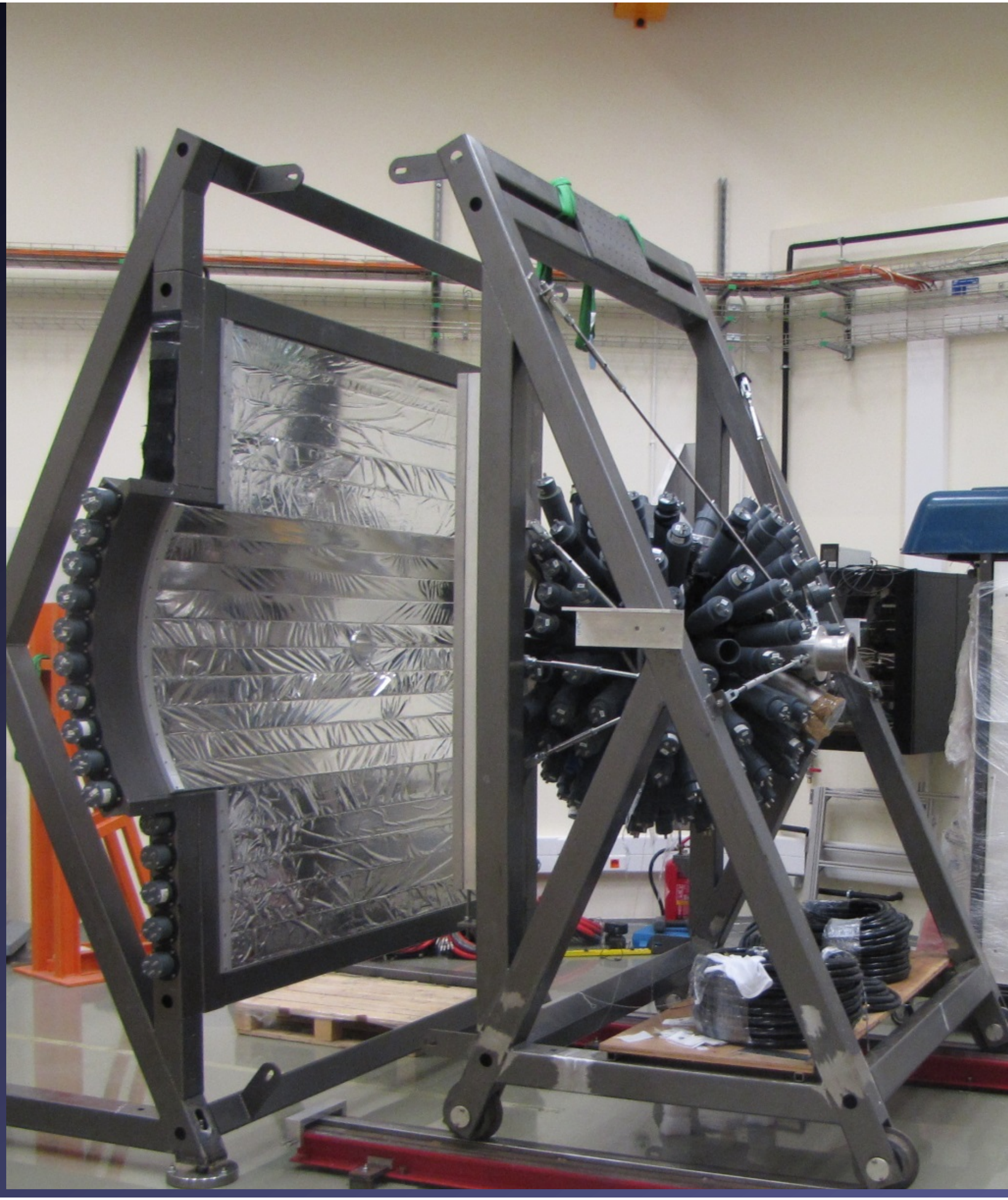
BINA Ball detector



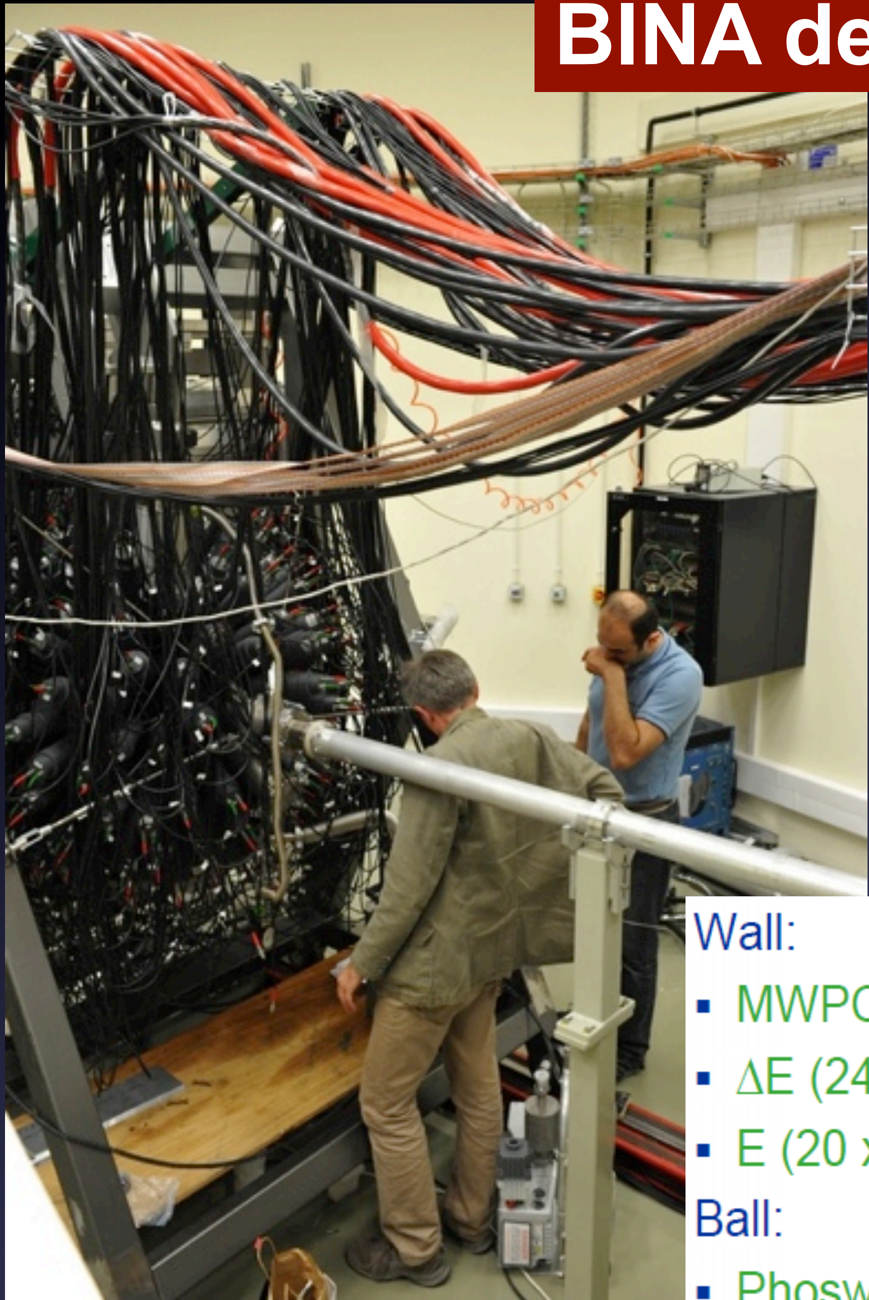
- 149 phoswich detectors (fast BC-408, slow BC-444).
- Thickness: ΔE: 1mm, E: 9 – 3 cm.
- Angular acceptance ~40°-160°.
- Exit window: aramica foil 50 μm .

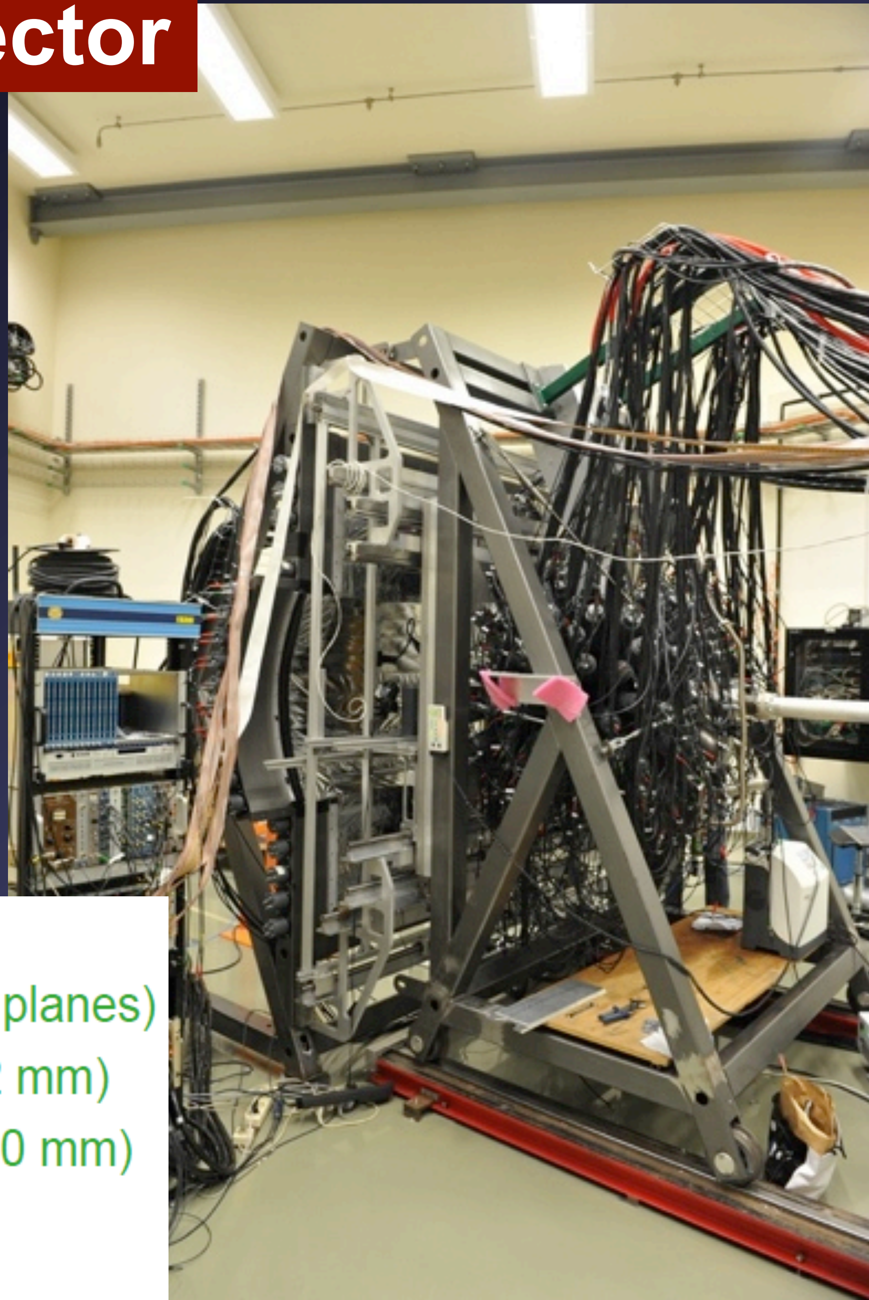






BINA detector



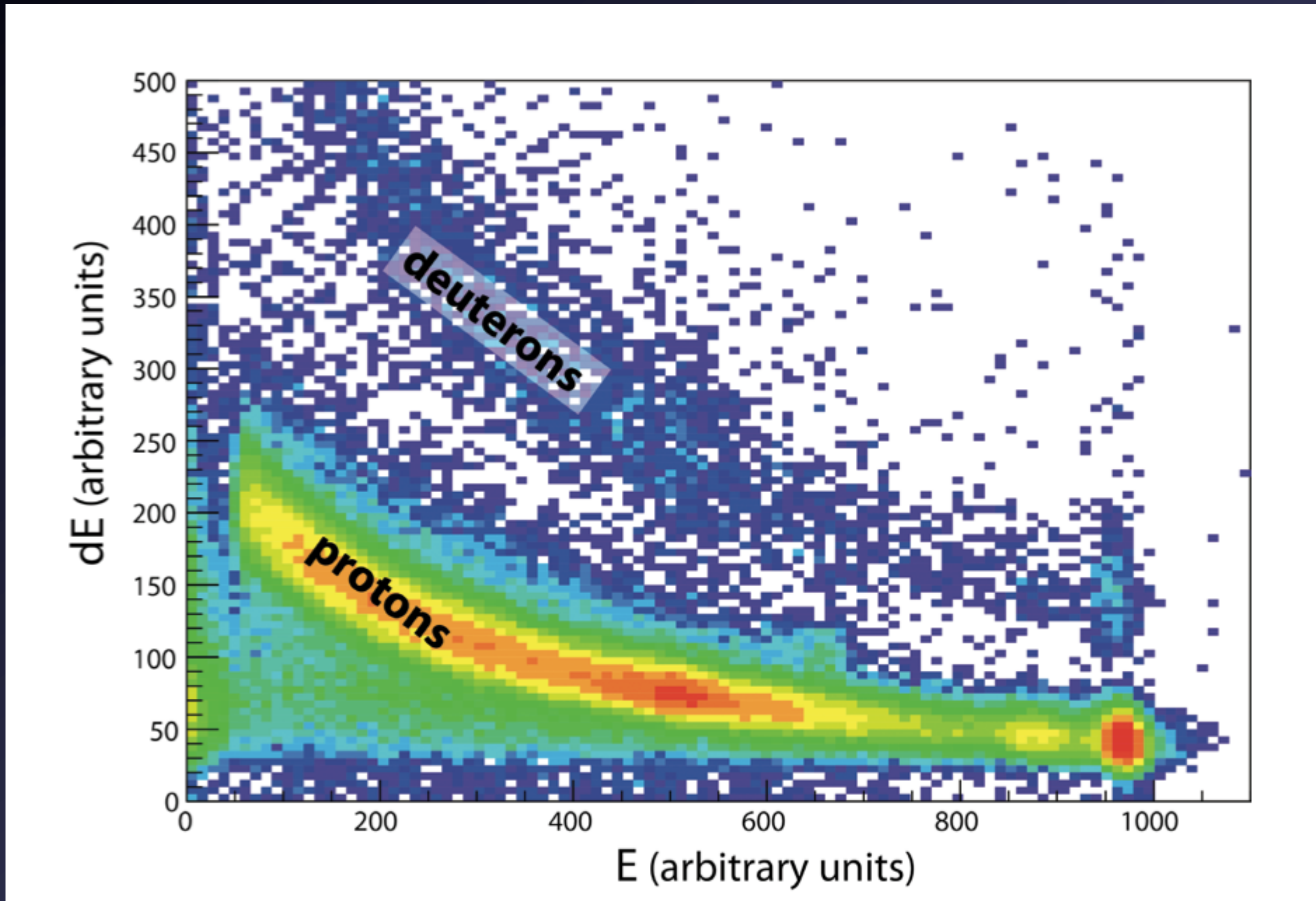


Wall:

- MWPC (3 planes)
- ΔE (24 x 2 mm)
- E (20 x 120 mm)

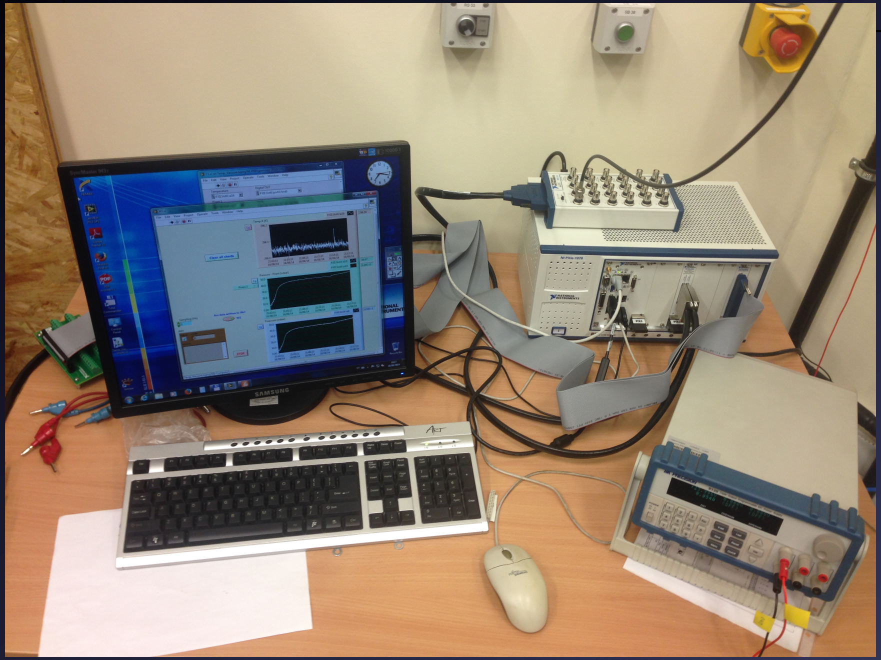
Ball:

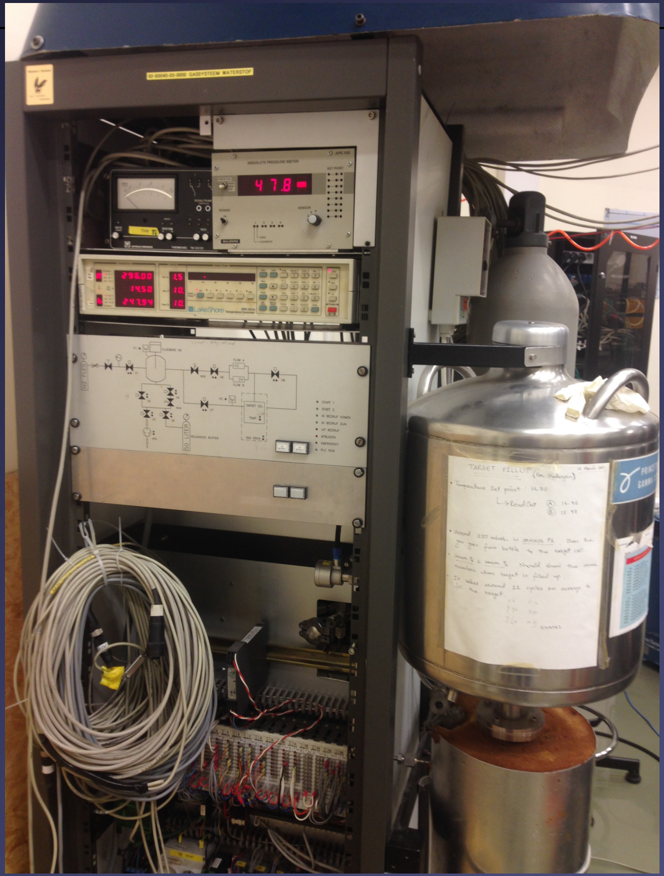
- Phoswich (149 x 90/30 mm)



BINA particle identification spectrum

Towards liquid deuterium target
PXI control system





- Readout and control of temperature (heater)
- Readout of vacuum pressure
- Process control - **new** – program prepared, integration with hardware in progress

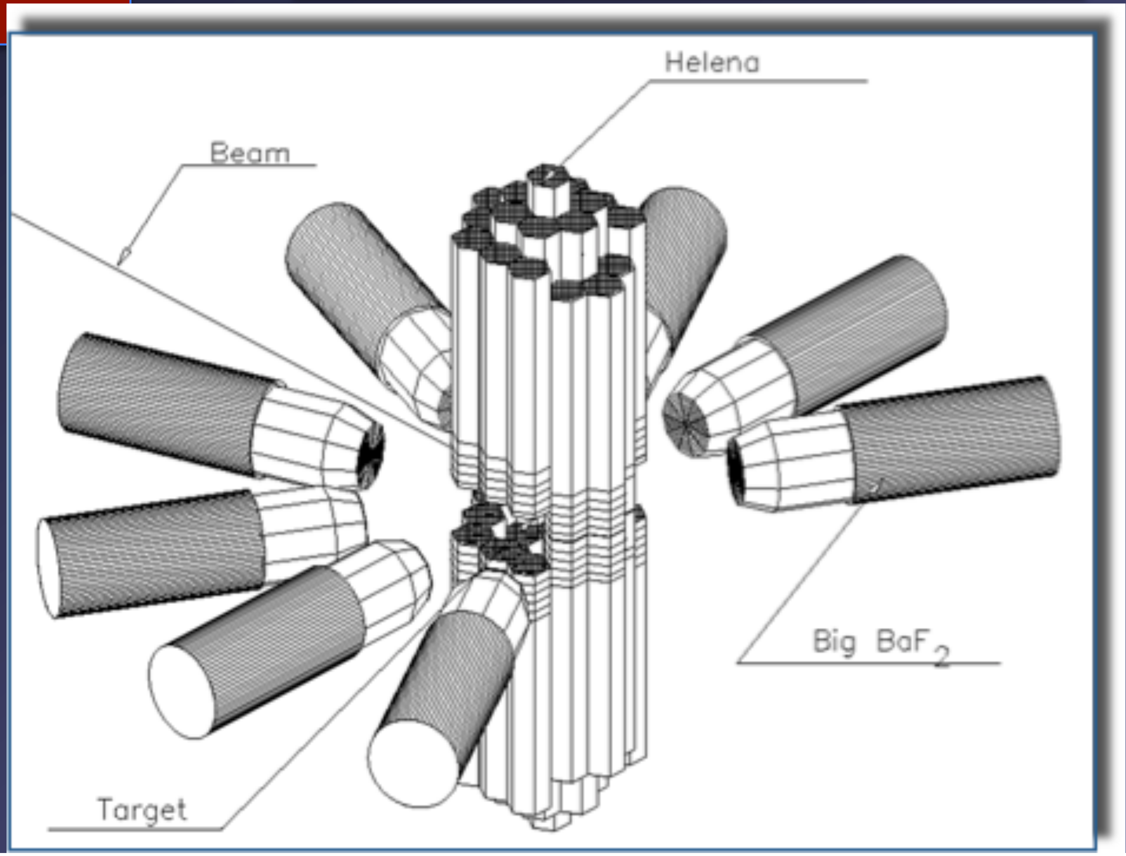
Under disscussion:
Future upgrade of BINA for polarized ^{3}He target

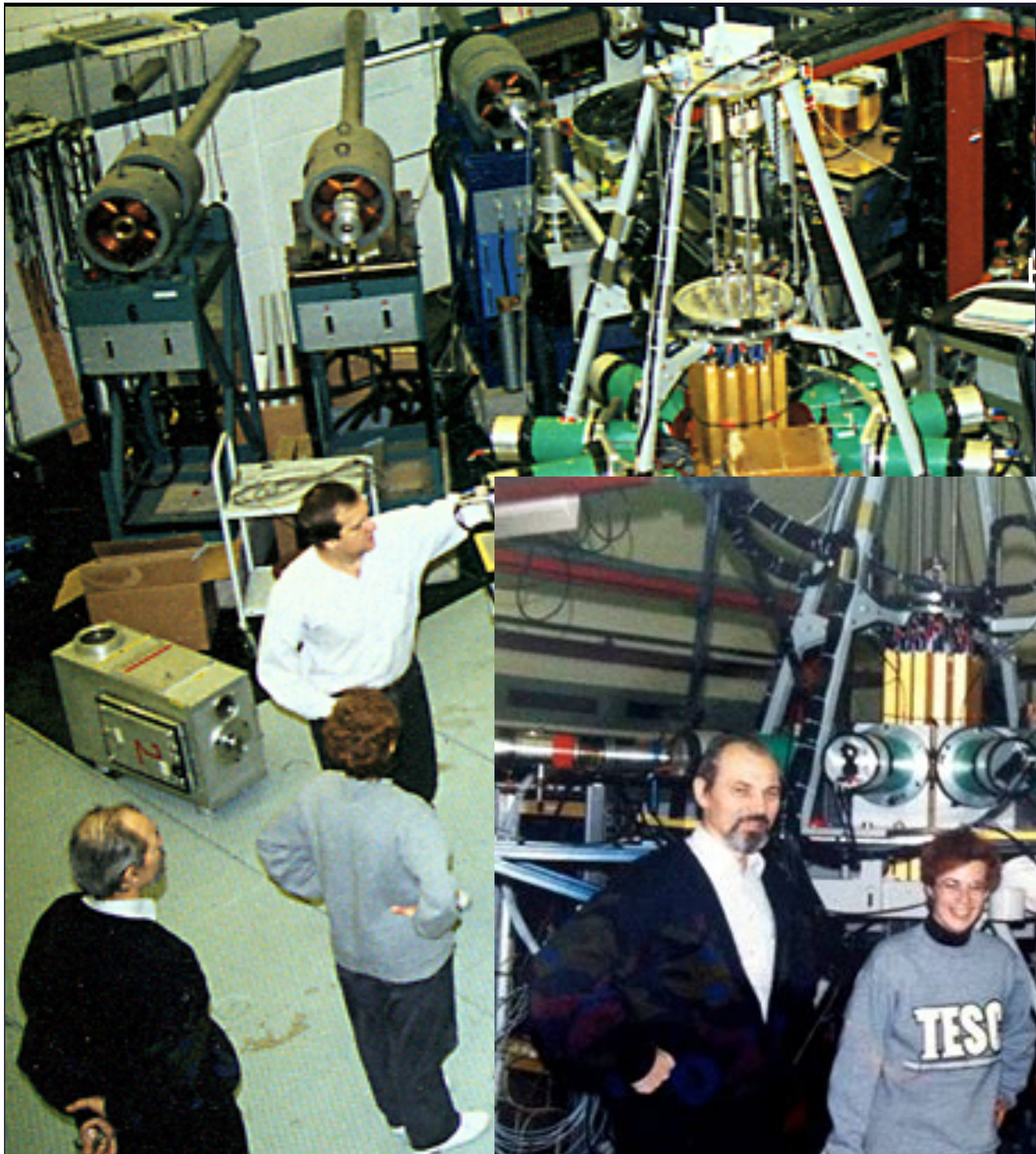
2. HECTOR array (High Energy gamma-ray deteCTOR)

8 large (Φ15cmx20cm) cristals of BaF2
2 MeV < Eγ<40 MeV
$\Delta E/E \approx 10\%$, $\Delta t < 1$ ns
(collaboration Copenhagen –Milano–Kraków)

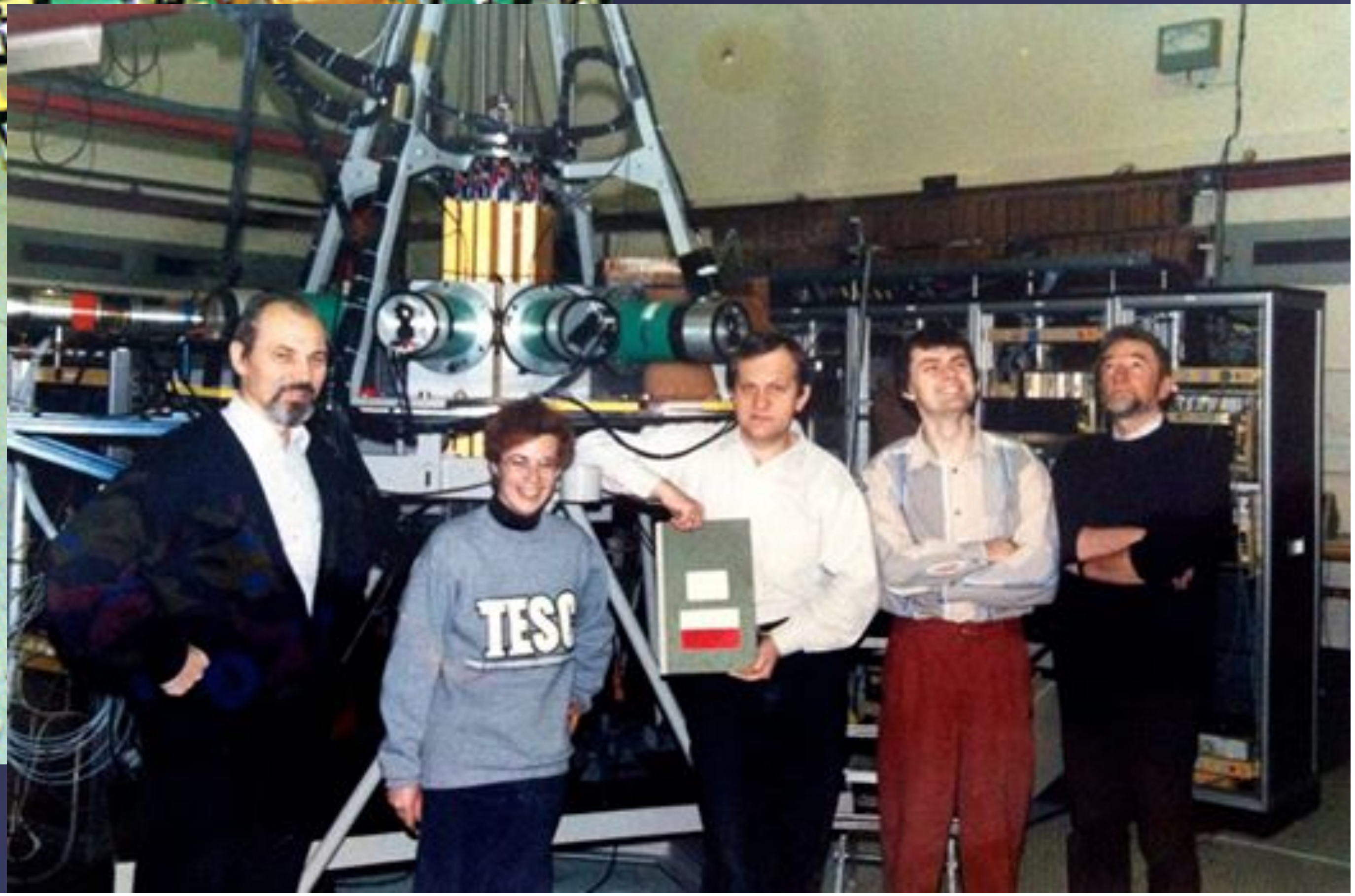
A.Maj, J.J.Gaardhoje, A.Atac, S.Mitarai, J.Nyberg, A.Virtanen, A.Bracco, F.Camera, B.Million, M.Pignanelli,
Nucl.Phys. A571, 185 (1994)

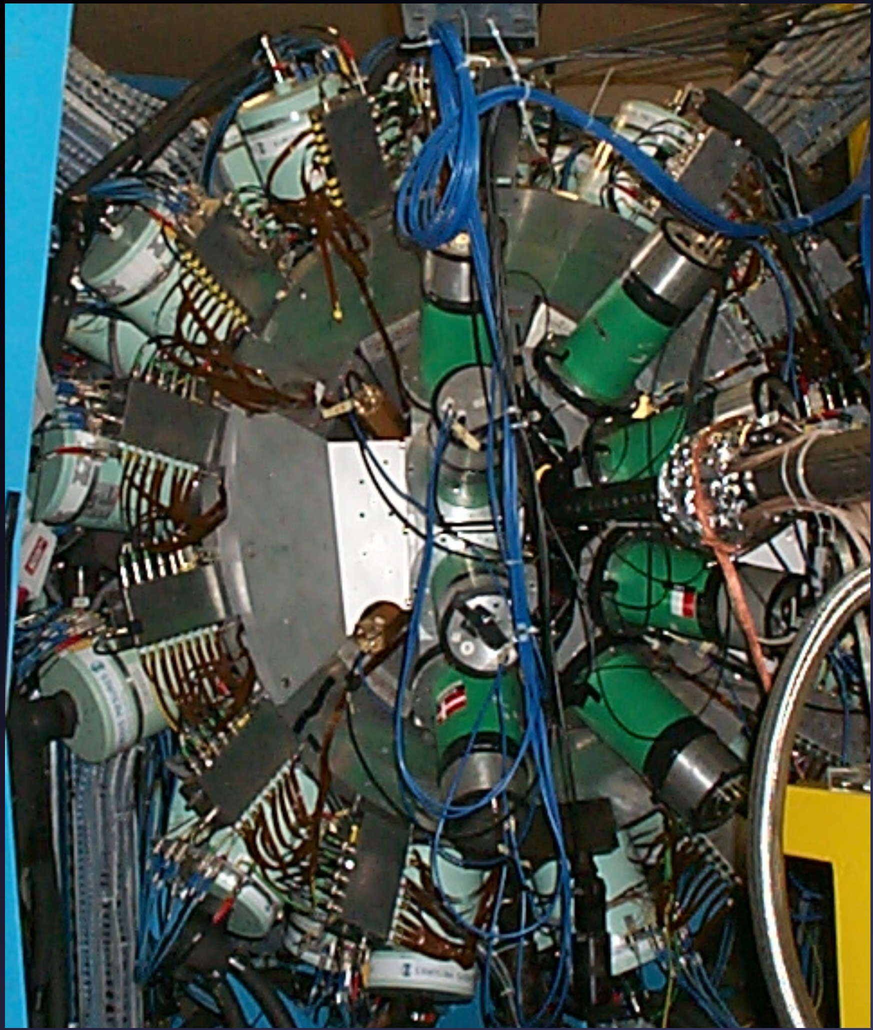
Multiplicity filter HELENA:
38 small BaF2



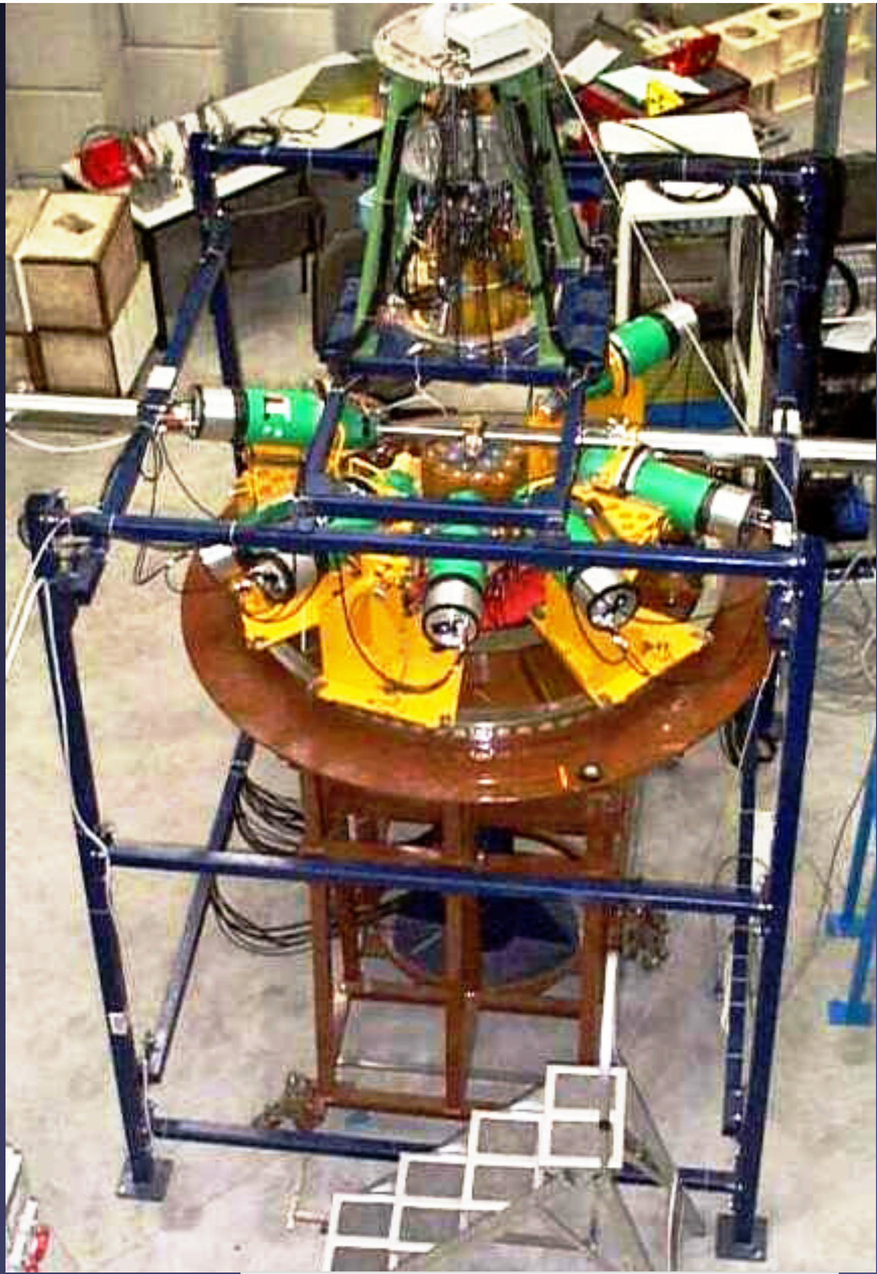


HECTOR@NBI, 1992



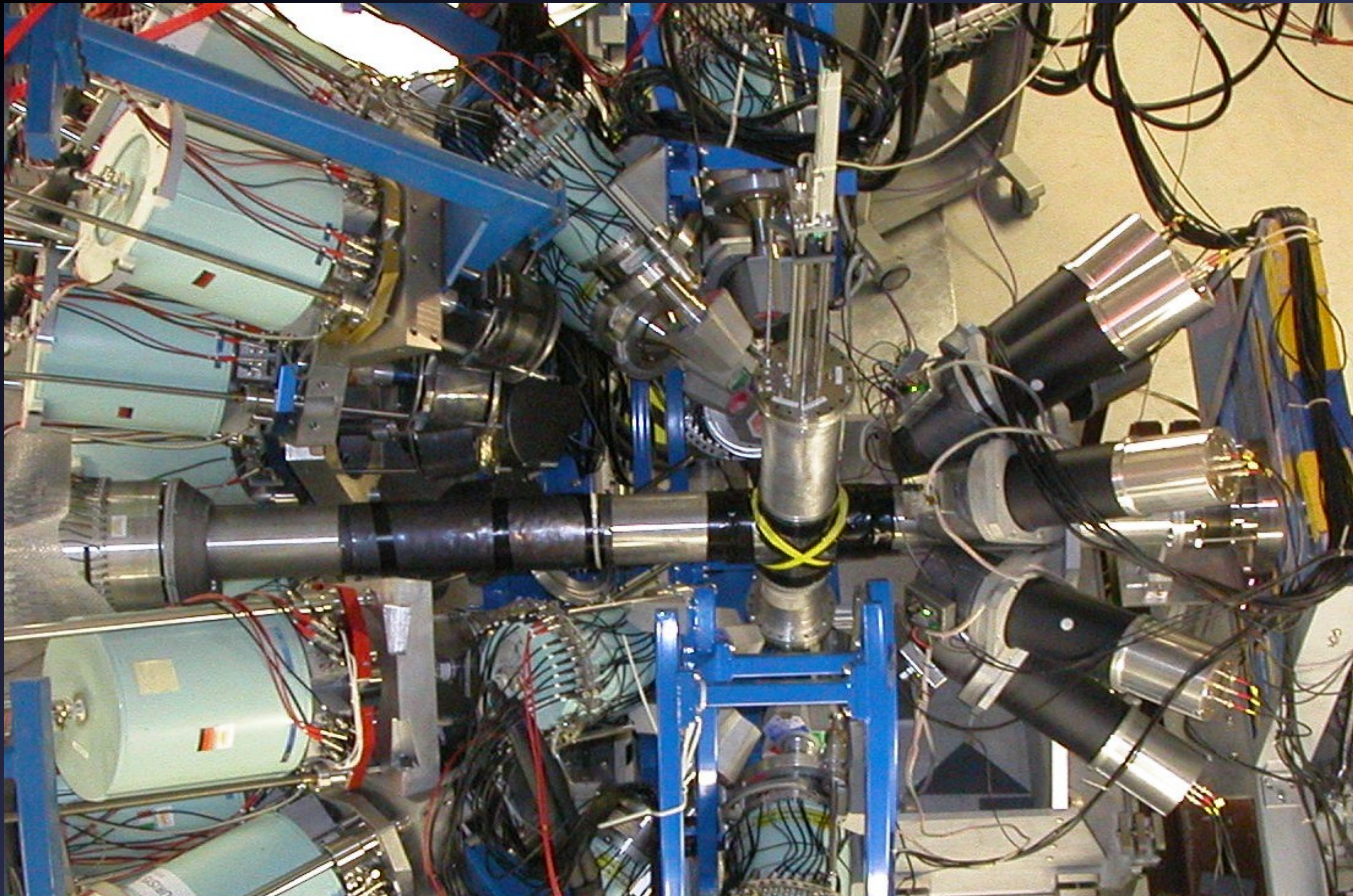


HECTOR with Euroball at Strasbourg, 2000



Hector at LNL Legnaro, 2004

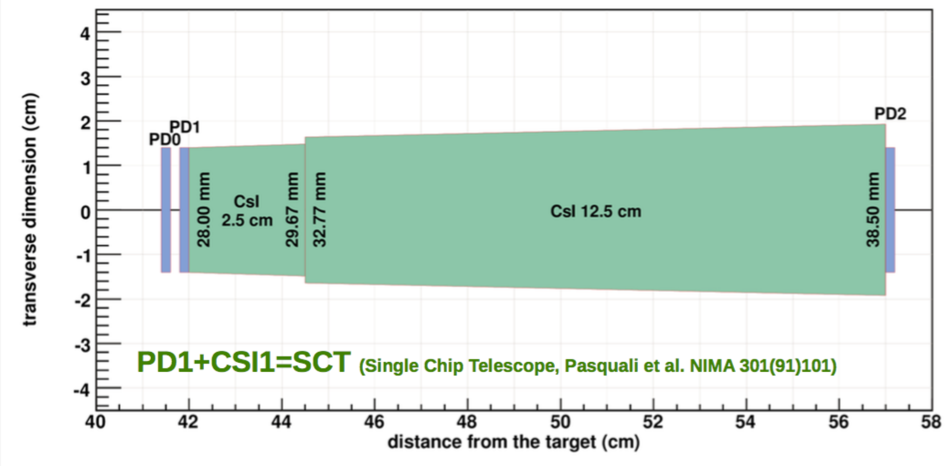
HECTOR+Prespec and HECTOR+AGATA@GSI, 2010-14



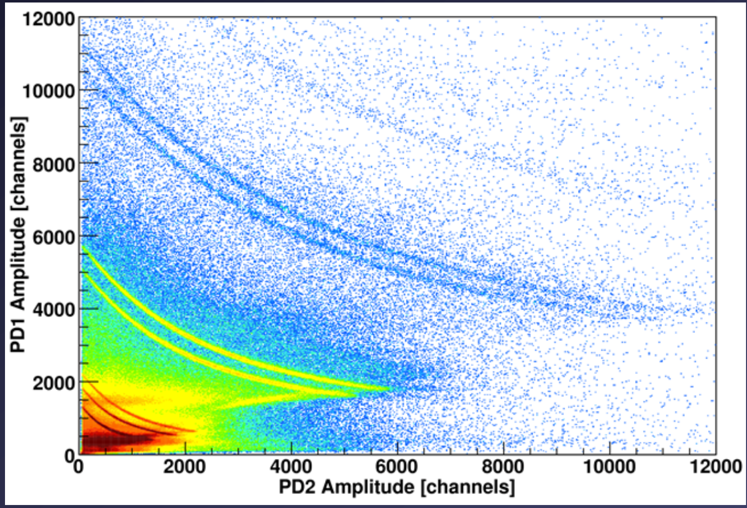
The HECTOR array arrived from GSI in May 2014 (after the AGATA@GSI campaign)

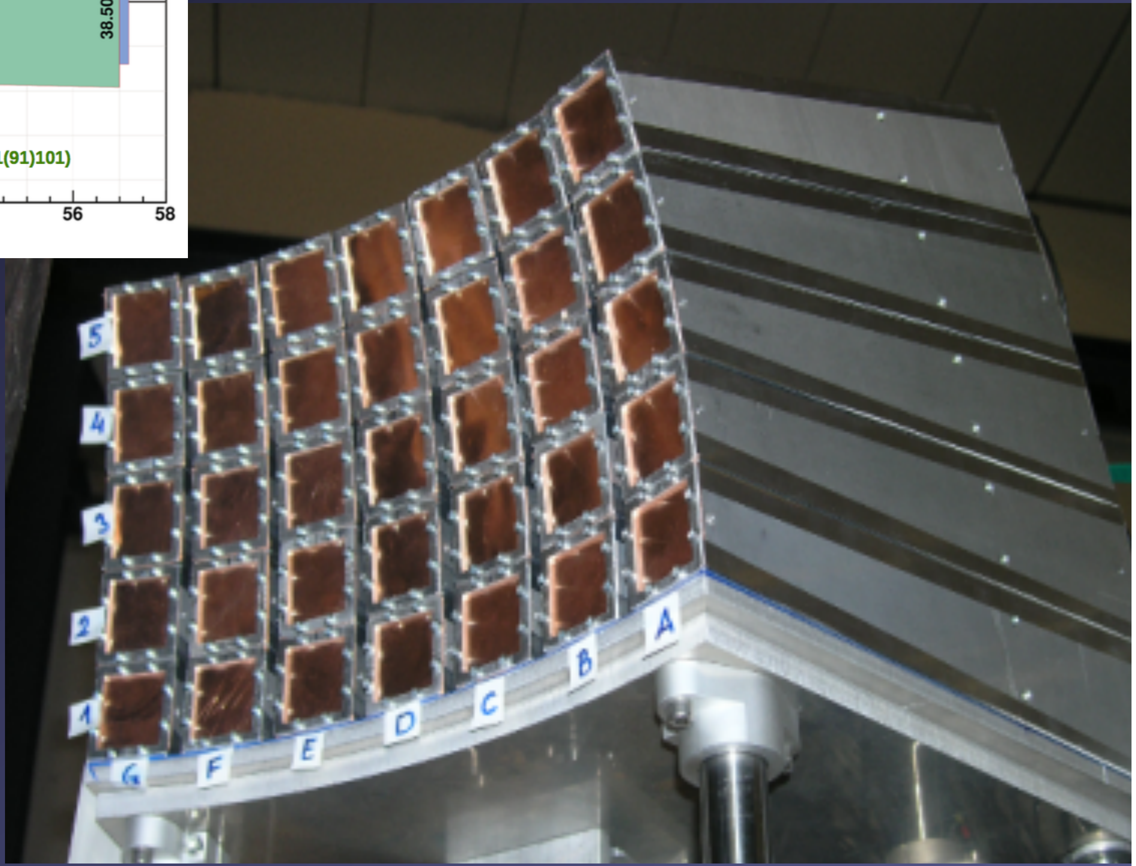
3. KRATTA array (Krakow triple telescope array)

35 triple CsI telescopes to measure the energy and angle of inelastically scattered protons

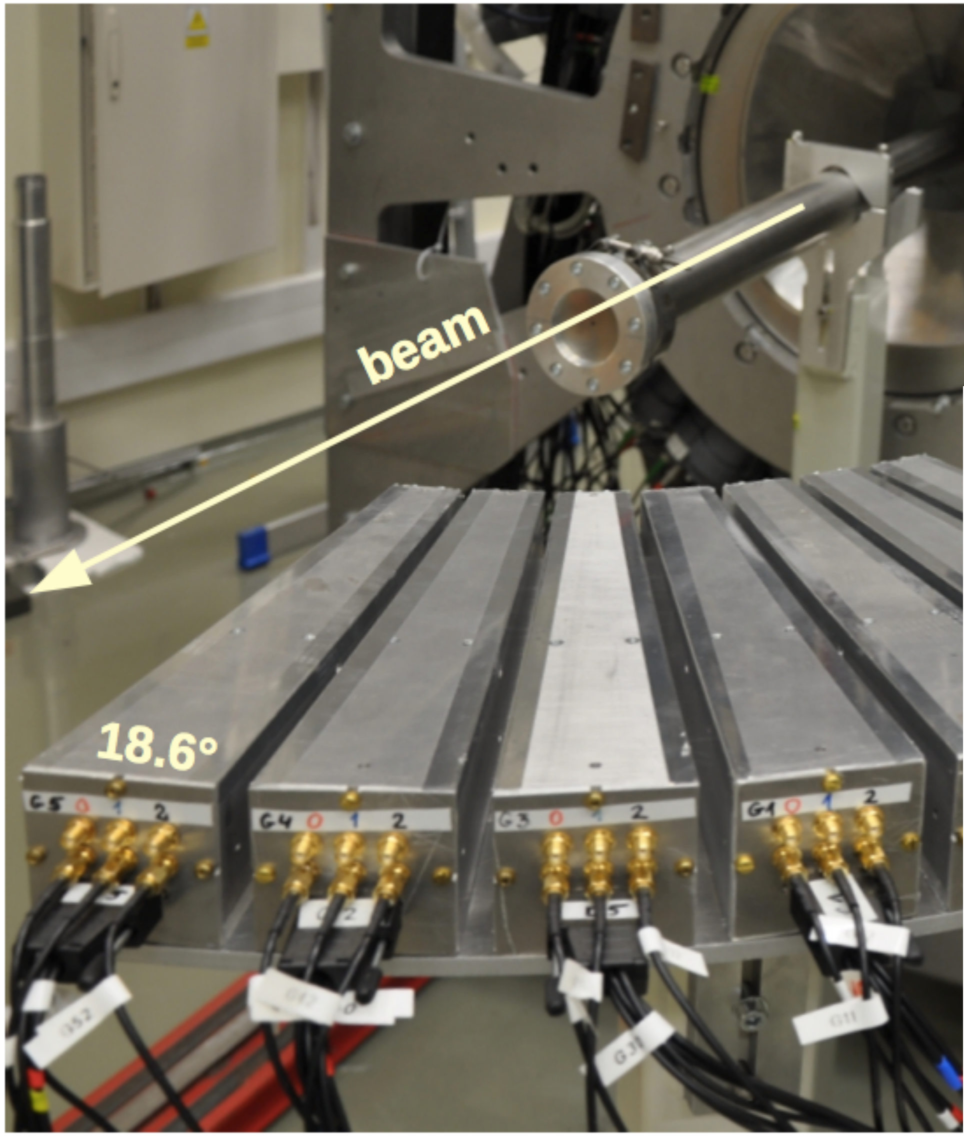


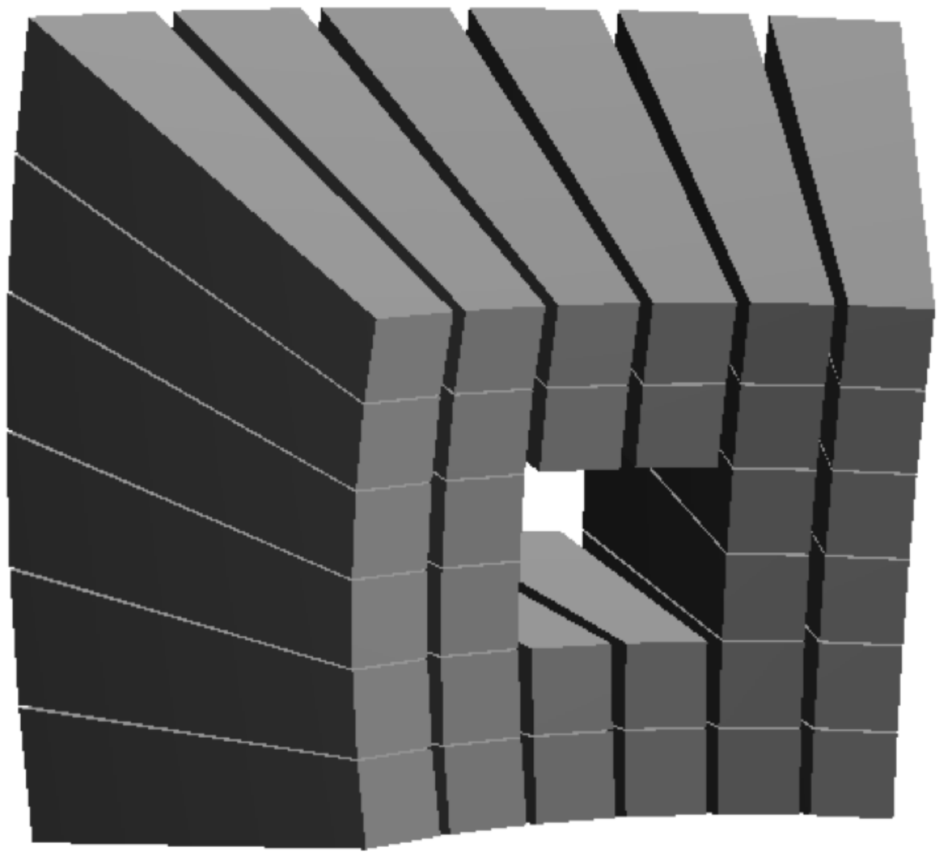
Fully digital ACQ





Different geometries of KRATTA possible

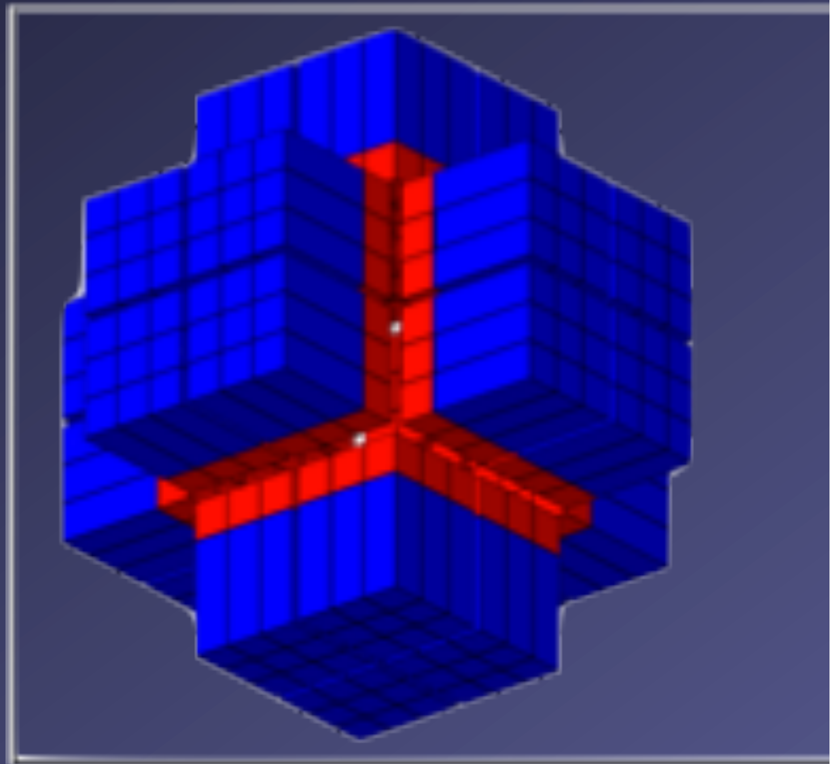




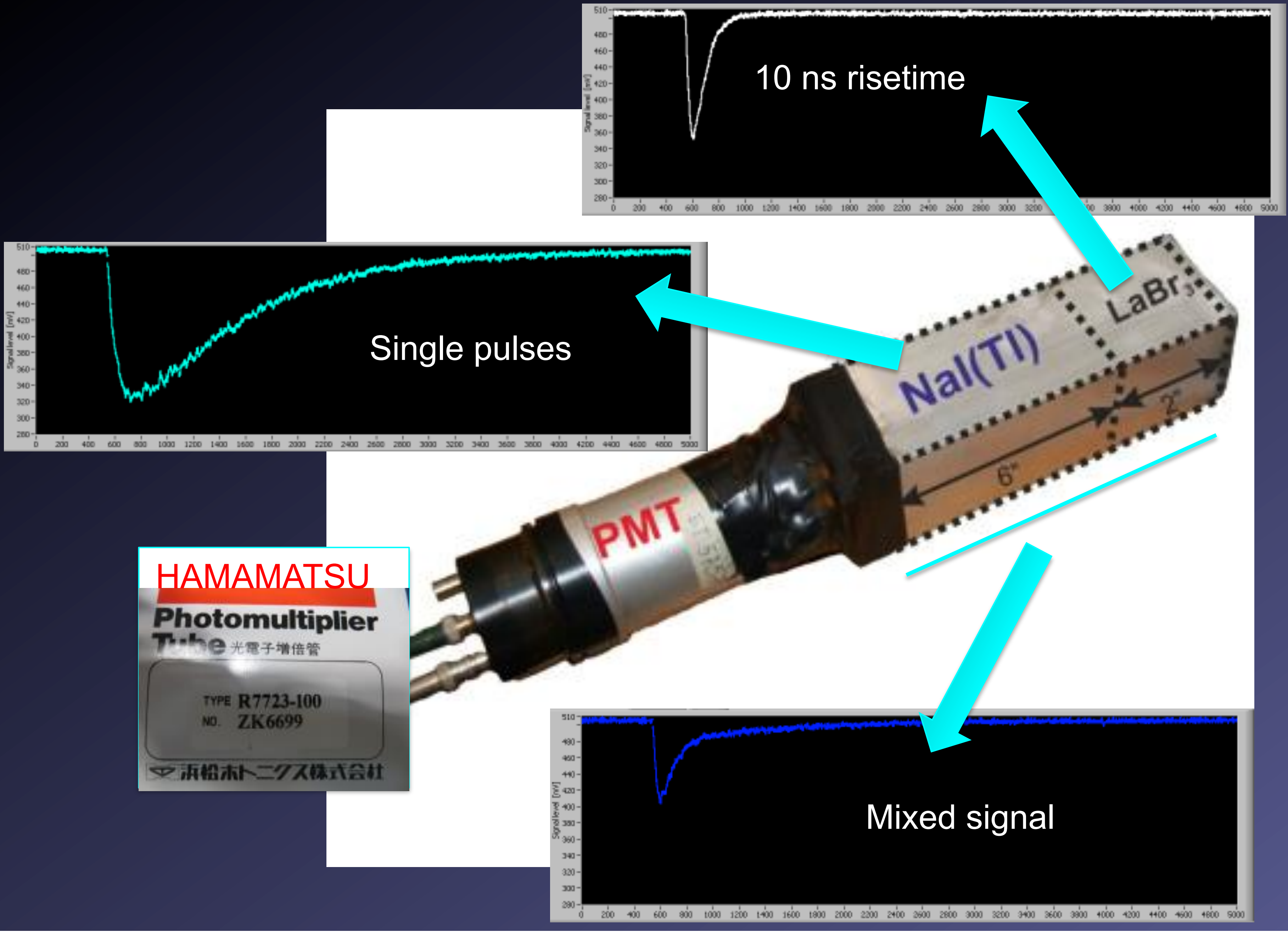
4. PARIS demonstrator: 1-4 clusters, each of 9 phoswich Labr3-NaI detectors

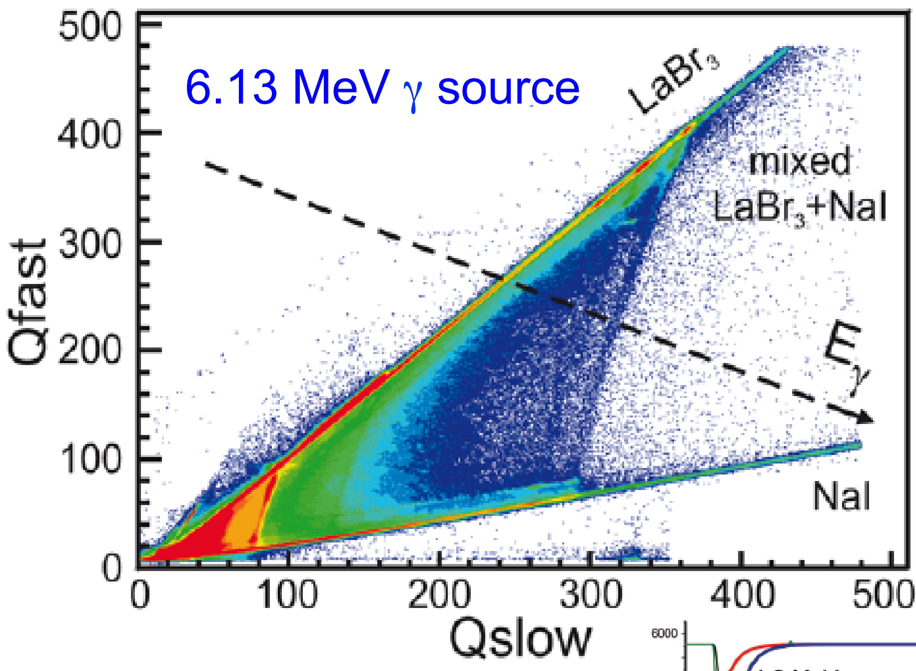
(available for some experimental campaigns)

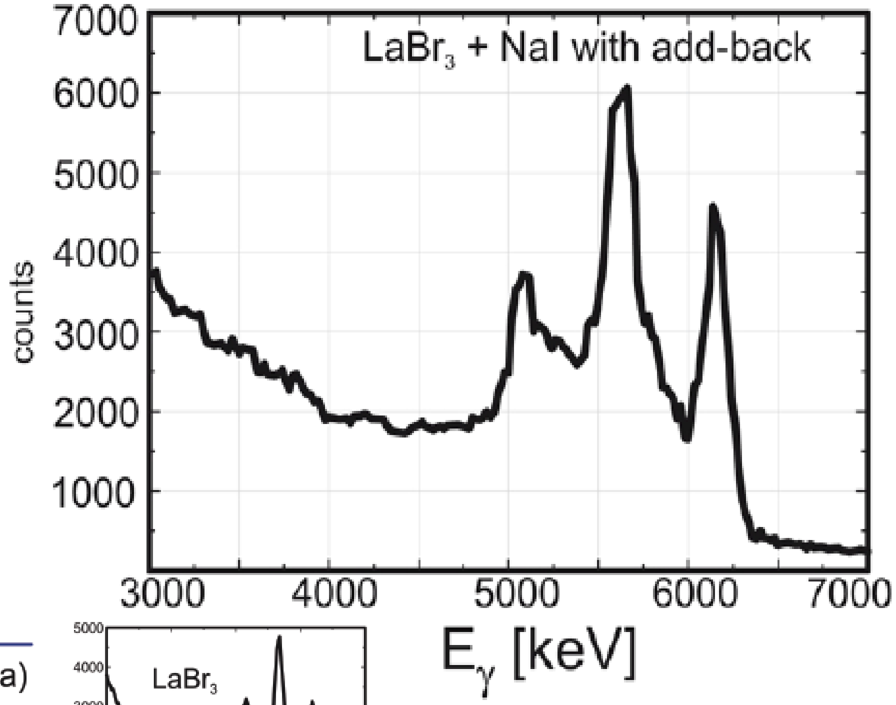
PHOTON ARRAY FOR STUDIES WITH RADIOACTIVE ION AND STABLE BEAMS

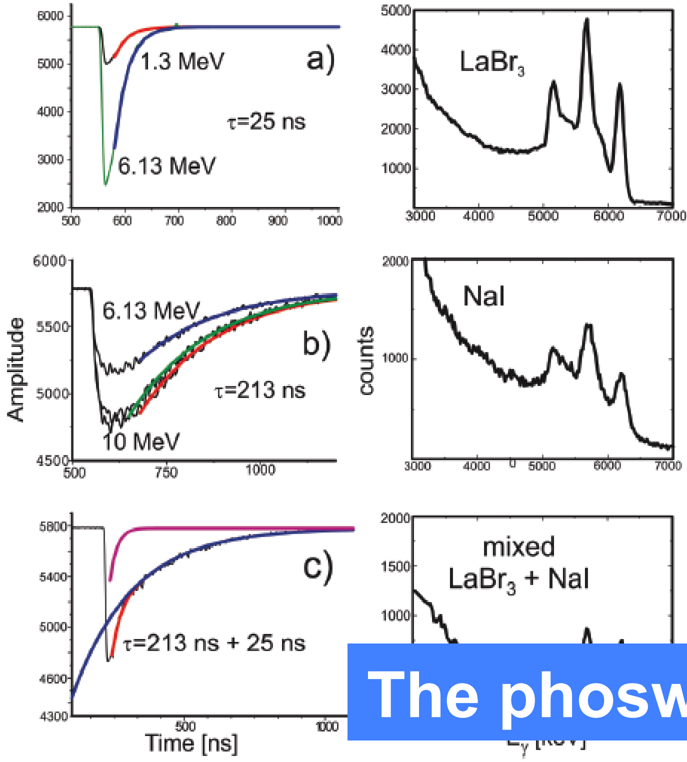


The PARIS PHOSWICH at work









A test measurement at IFJ PAN, Kraków (2011)

- Sources
- proton beam

LaBr3 resolution (seen through 6” long NaI): ca. 4%

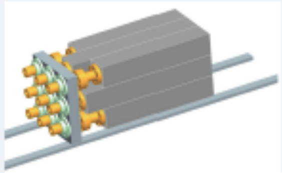
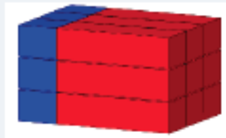
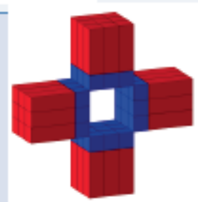
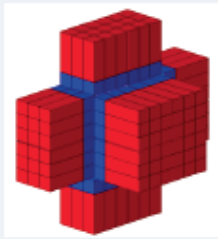
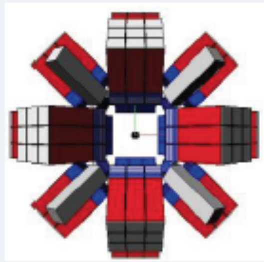
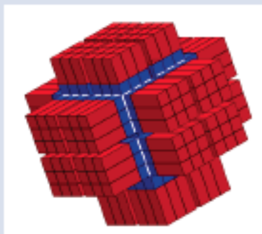
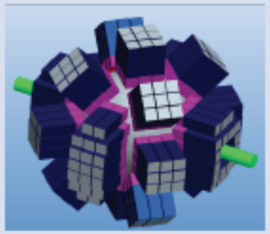
M. Zieblinski et al.,
Acta Phys.Pol. B44, 651

The phoswich concept works!

PARIS Demonstrator MoU (Primary site: GANIL/SPIRAL2, additional sites: IPN Orsay, Krakow, LNL Legnaro, TIFR Mumbai)

MoU on PARIS Demonstrator (Phase 2) was prepared and agreed to be signed by IN2P3 (France), COPIN (Poland),GANIL/SPIRAL2 (France), TIFR/BARC/VECC (India), IFIN HH (Romania), INFN (Italy), Bulgaria, UK, Turkey

PARIS phases and cost estimates

Phase 1 **2011/2012** PARIS cluster	1 cluster: 9 phoswiches	 	250 k€	**Decided** Funds: SP2PP, ANR, Orsay, Strasbourg, Kraków, Mumbai. Tests in-beam and with sources
Phase 2 **2015** **PARIS Demonstrator**	5 clusters: 45 phoswiches		1100 k€	**Only if Phase1 validated** Funds: MoU. Ph1Day1 exp@S3
Phase 3 **2017** **PARIS 2π**	12 clusters: 108 phoswiches	 	≈ 2 M€	**Only if Phase2 validated** Funds: MoU, PARIS consortium. Ph2Day1 exp. with AGATA and GASPARD Other exp.
Phase 4 **≈2019** **PARIS 4π**	≥24 clusters: ≥216 phoswiches	 	≈ 4 M€	**Only if Phase3 validated** Funds: PARIS consortium. Regular experiments in various labs

5. Large reaction chamber (with entrances for gamma detectors)

6. Other smaller detector systems:

- 2 Ge detectors with ACS shields
- 1 large volume (3.5”x8”) LaBr3
- 1 small volume (2”x2”x2”) Labr3
- 1 large volume (4”x4”) BGO
- Small multiwire chamber
- Set of Si-detectors
- …..

Physics Programme

International Advisory Committee

- Faical Azaiez (IPN, Orsay, France)
- Angela Bracco (University of Milano and INFN, Italy)
- Bogdan Fornal (IFJ PAN, Kraków, Poland) - co-chair
- Zsolt Fulop (ATOMKI, Debrecen, Hungary)
- Muhsin Harakeh (KVI, Groningen, Netherlands) - chair
- Robert Janssens (Argonne National Laboratory, USA)
- Stanisław Kistryn (Jagiellonian University, Kraków, Poland)
- Marek Lewitowicz (GANIL, Caen, France)
- Adam Maj (IFJ PAN, Kraków, Poland)
- Krzysztof Rusek (Warsaw University, Poland)
- Hideyuki Sakai (RIKEN, Japan)
- Nicolae Victor Zamfir (IFIN-HH, Bucharest, Romania)
- Wiktor Zipper (University of Silesia, Katowice, Poland)

3 meetings of IAC took place
Status of the CCB project was reviewed
LoIs were discussed and recommendations given

CCB-IAC conlusions

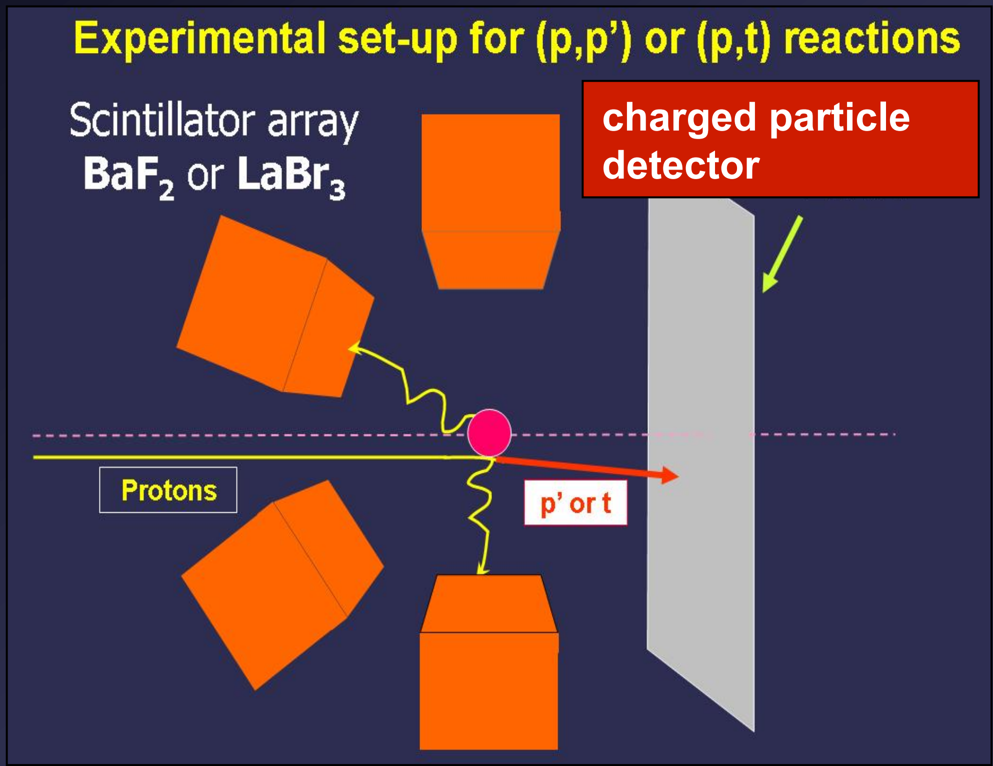
The IAC of CCB was impressed by the developments made at CCB since the previous meeting that was held a year ago. These rapid developments include the therapy part and the basic science part as well. The installation of the infrastructure evolved very fast and by now the Centre faces the first problems of the beam-time distribution and assignment to either proton therapy or fundamental and applied physics programmes. The first scientific and industrial connections have also been established. In addition, it is foreseen, from the report given, that the second gantry will be operational in due time in 2015.

CCB-IAC gave also detailed opinion about various proposals presented and reccomend their priorities

LoIs and proposals submitted

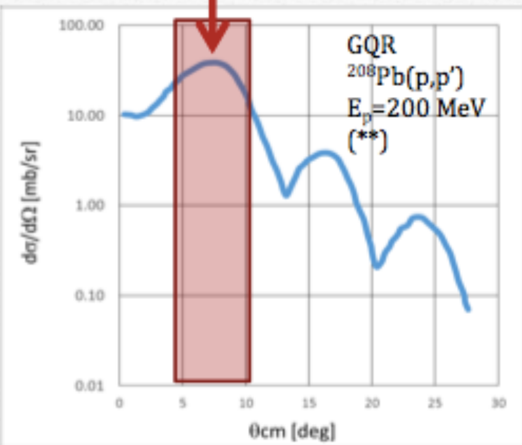
Innovative perspectives for studies on proton-induced spallation at CCB	D. Mancusi, Ch. Schmitt et al.
Investigation of the mechanism of proton-induced reactions leading to the continuum	B. Kamys et al.
The gamma decay from high-lying states and giant resonances excited via (p, p'γ) at beam 70-200 MeV	F. Crespi, M. Kmiecik et al.
Study of deeply bound 1s-proton-hole state decay in ^{11}B and two-alpha cluster wave function in ^{12}C by using ^{12}C(p,2p)^{11}B and ^{12}C(p,αp)^{8}Be reactions	A. Bracco, B, Fornal, N. Cieplicka et al.
Dynamics of few-nucleon systems	E. Stephan, A. Kozela, S. Kistryn et al.
Investigation of gamma emission in experimental modelling of hadron therapy	A. Wronska, A. Magiera, P. Bednarczyk et a
Proton irradiation of CALIFA detection modules at the Bronowice Cyclotron Centre (CCB)	D. Cortina-Gil, J. Cederkal, B. Szpak et al.
Physics of the bremsstrahlung photons in nuclear processes	S. Maydanyuk et al.

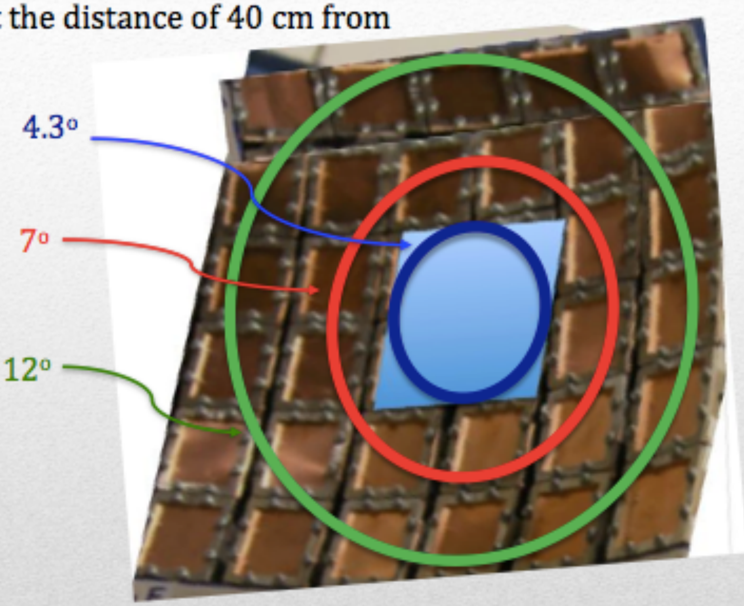
Study of gamma-decay of collective modes (GDR, GQR, PDR) excited in proton-induced reactions:
(p,p') or (p,t) – reactions at 100-230 MeV;.
Coord. M. Kmiecik (Krakow) and F. Crespi (Milano)

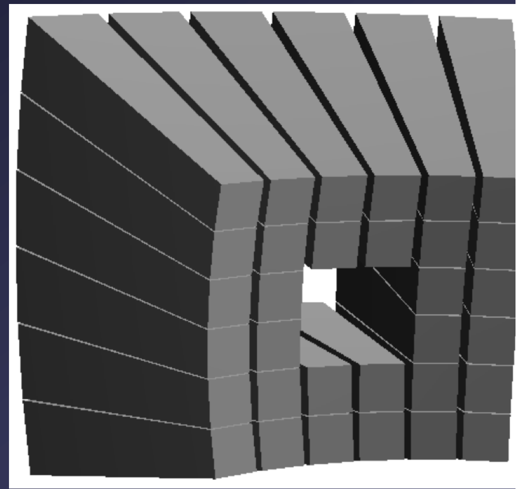


Gamma Decay of GQR – F. Crespi & M. Kmiecik

- ❑ **KRATTA after modifications** *(removing 4 detectors in the center and adding one row)* at the distance of 40 cm from target

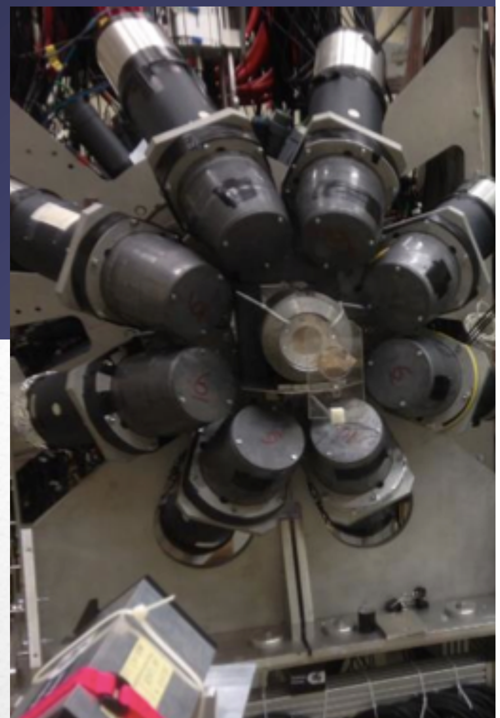






- ❑ Solid angle of the „red" (corresponding to ca. 7°): ca. 50 msr (covers angles from ca. 4.5° to ca. 10°)
- ❑ The „green" at ca. 12° can be used to determine the background
- ❑ The **hole in the center** (with the radius at least of 4.3°) should be suffcient to let the direct beam through.

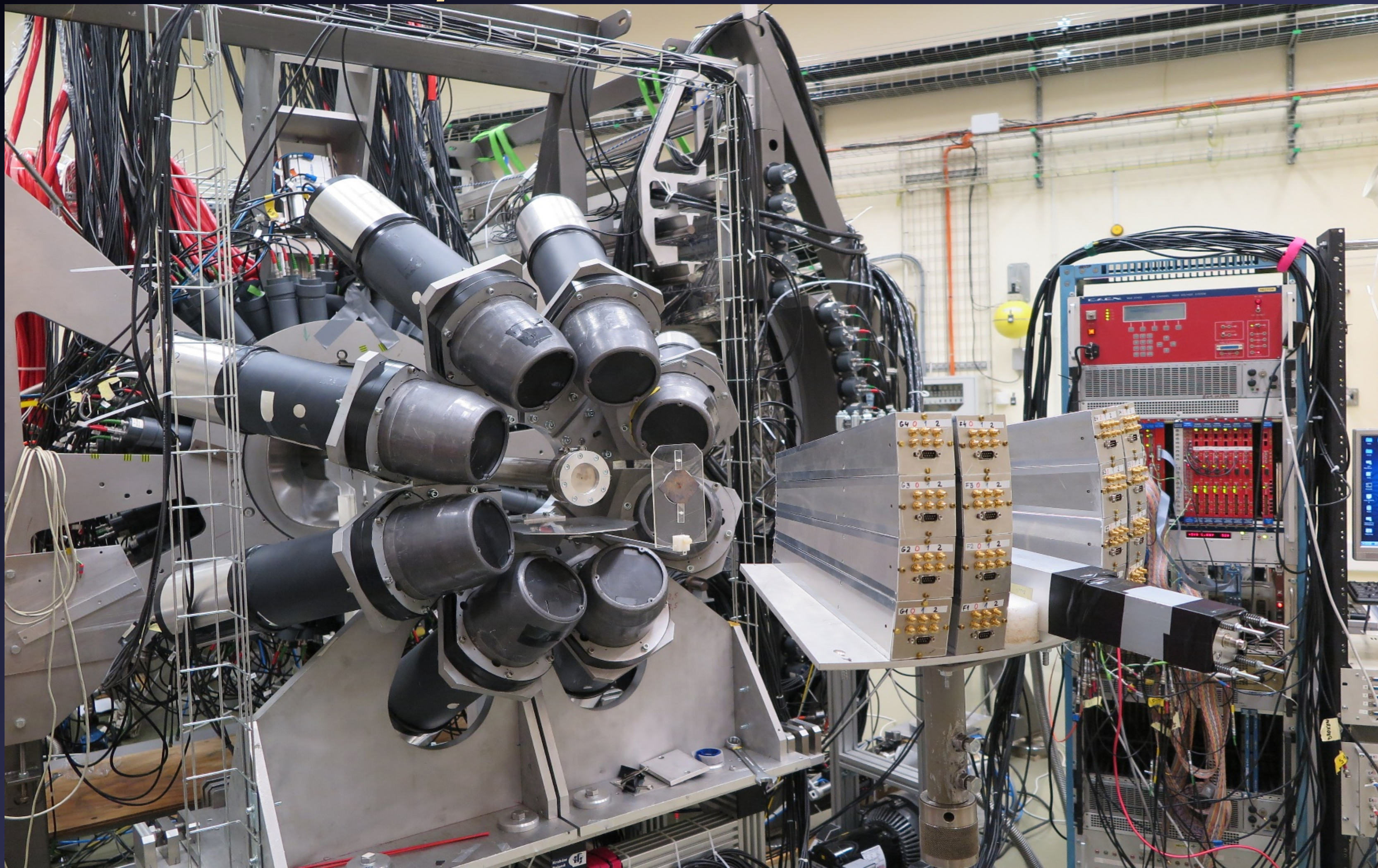
- ❑ The **KRATTA** array for the measurement of the scattered protons
  - ➢ Modification of the original geometry → →
  - ➢ For the study of pygmy states it is important to have an angular opening (0.5-1 degree) for the detection of the scattered protons. *We consider to add a plastic strip detector in front of KRATTA, to improve the angular resolution.*
- ❑ The **HECTOR** array for the measurement of gamma-rays → →



Test measurement of the HECTOR-KRATTA detector system

Was performed 20-31 October 2014…

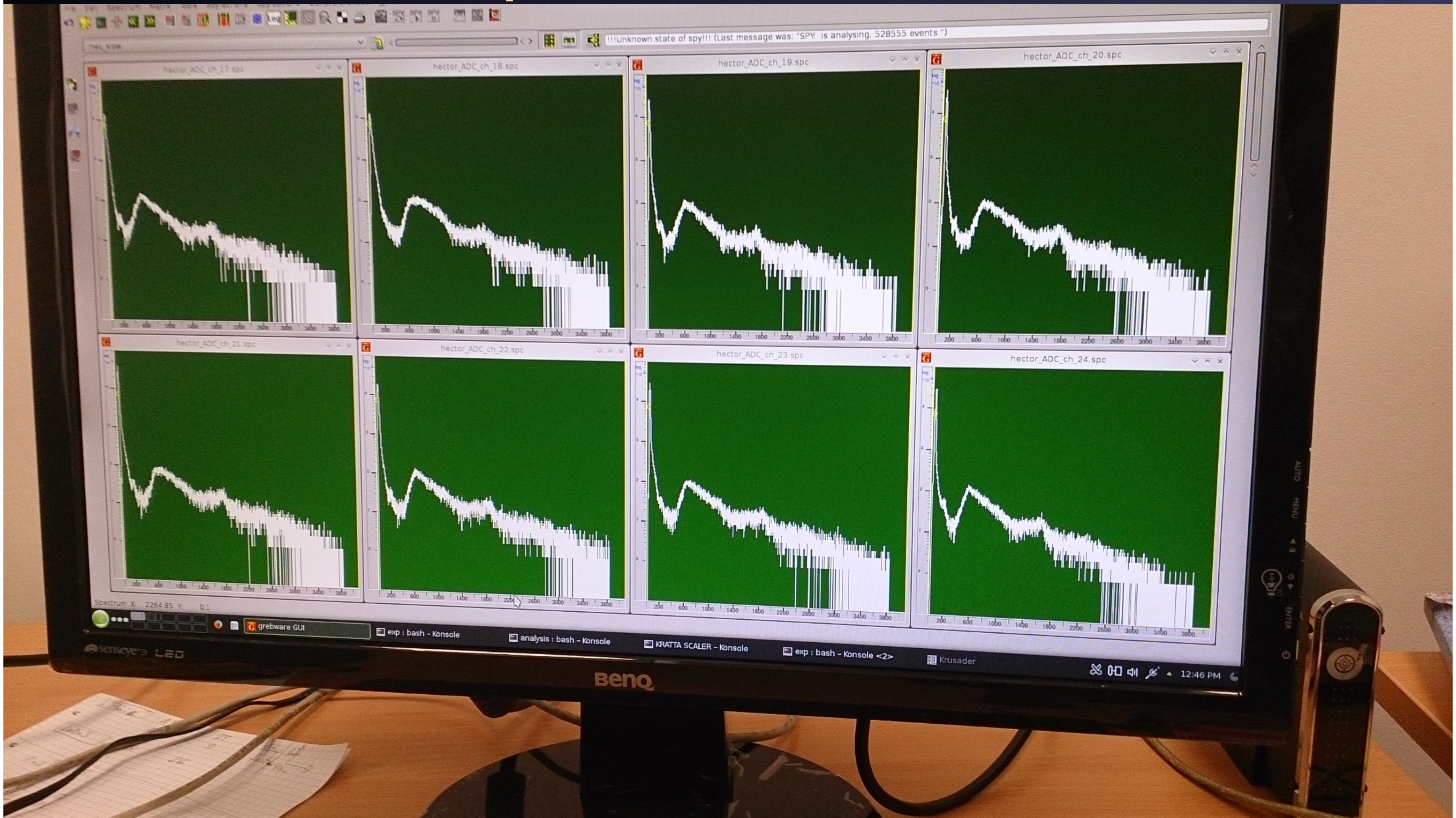
70 MeV p on ^{12}C, 150 MeV on ^{208}Pb



Test measurement of the HECTOR-KRATTA detector system

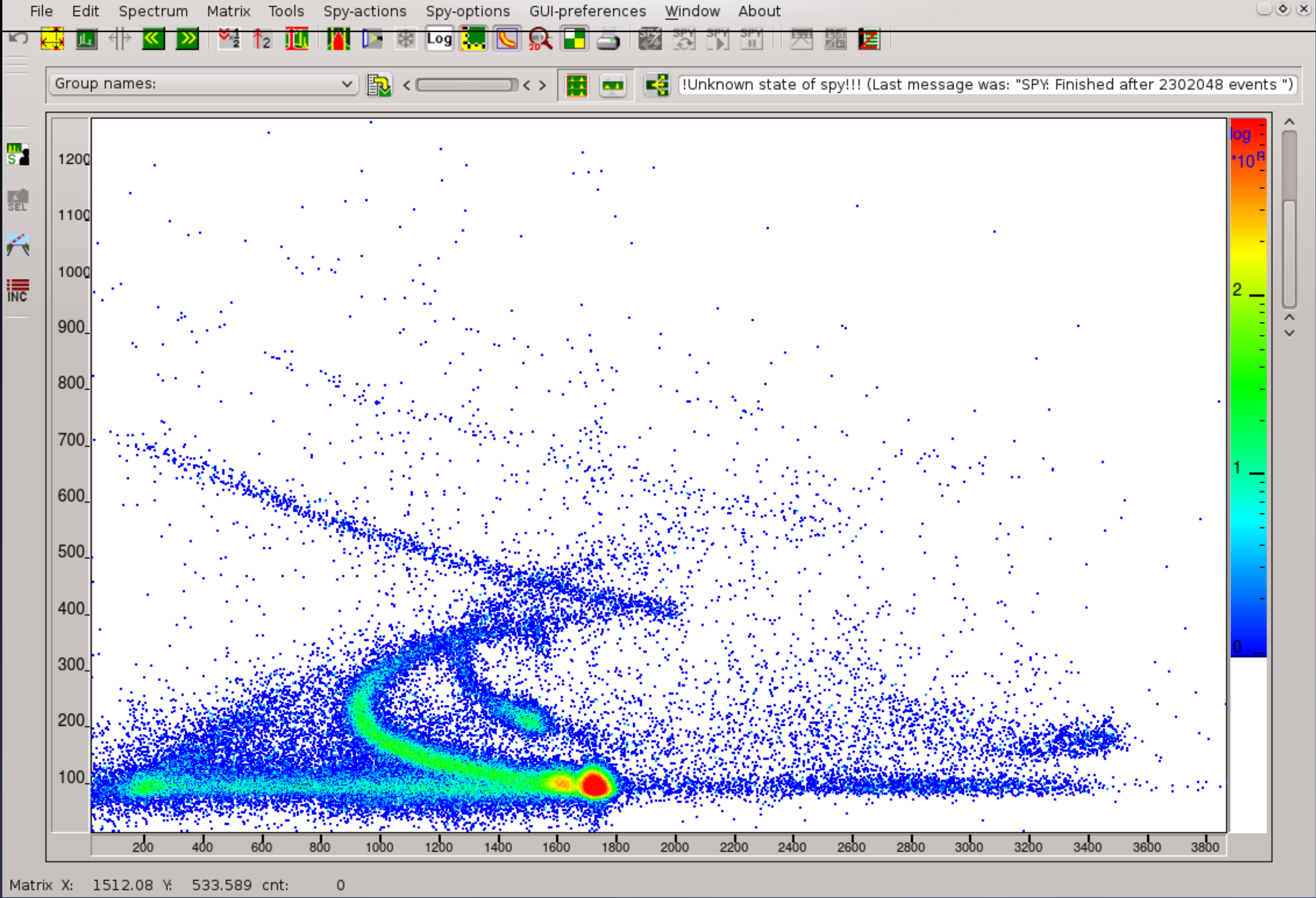
…was performed 20-31 October 2014…

70 MeV p on ^{12}C, 150 MeV on ^{208}Pb

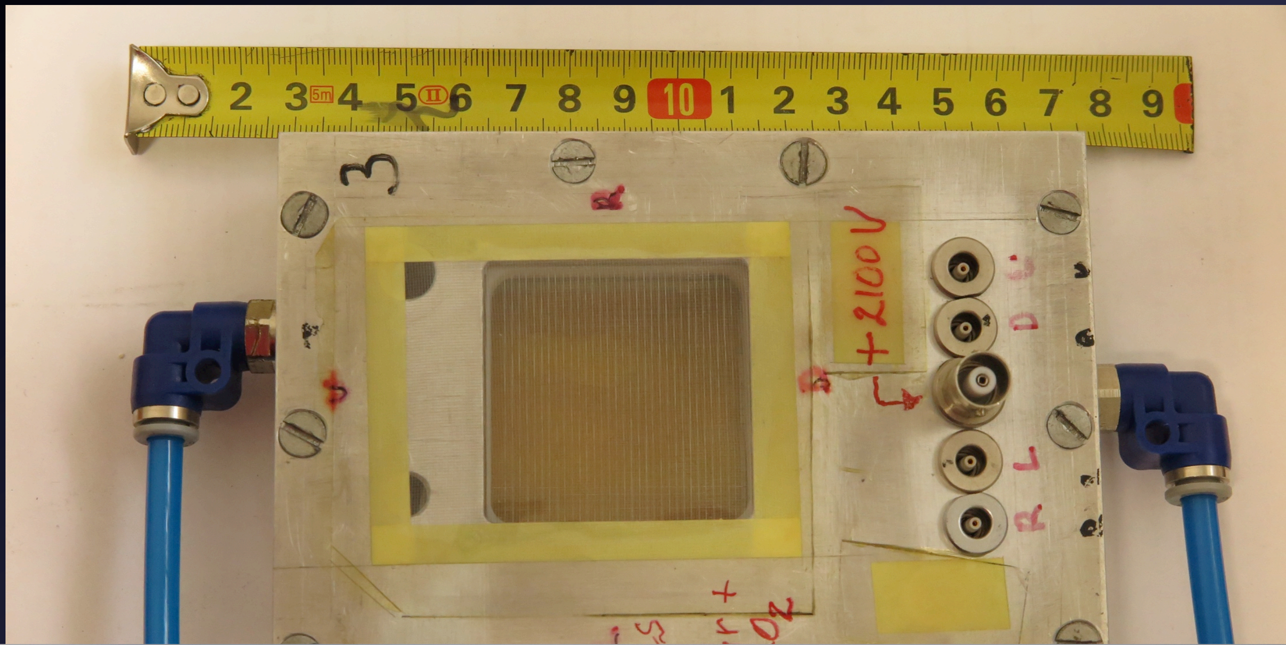


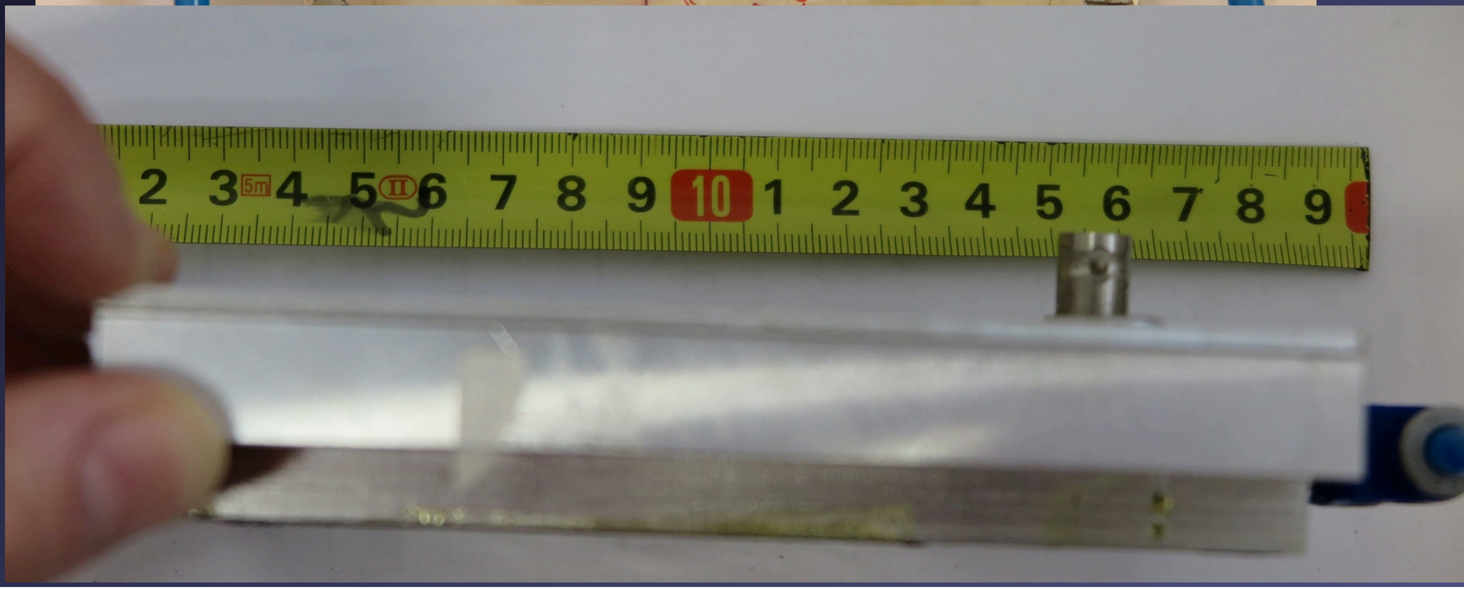
Test measurement of the HECTOR-KRATTA detector system

70 MeV p on ^{12}C



Testing a multiwire chambar from ATOMKI, to improve the angular resolution of KRATTA





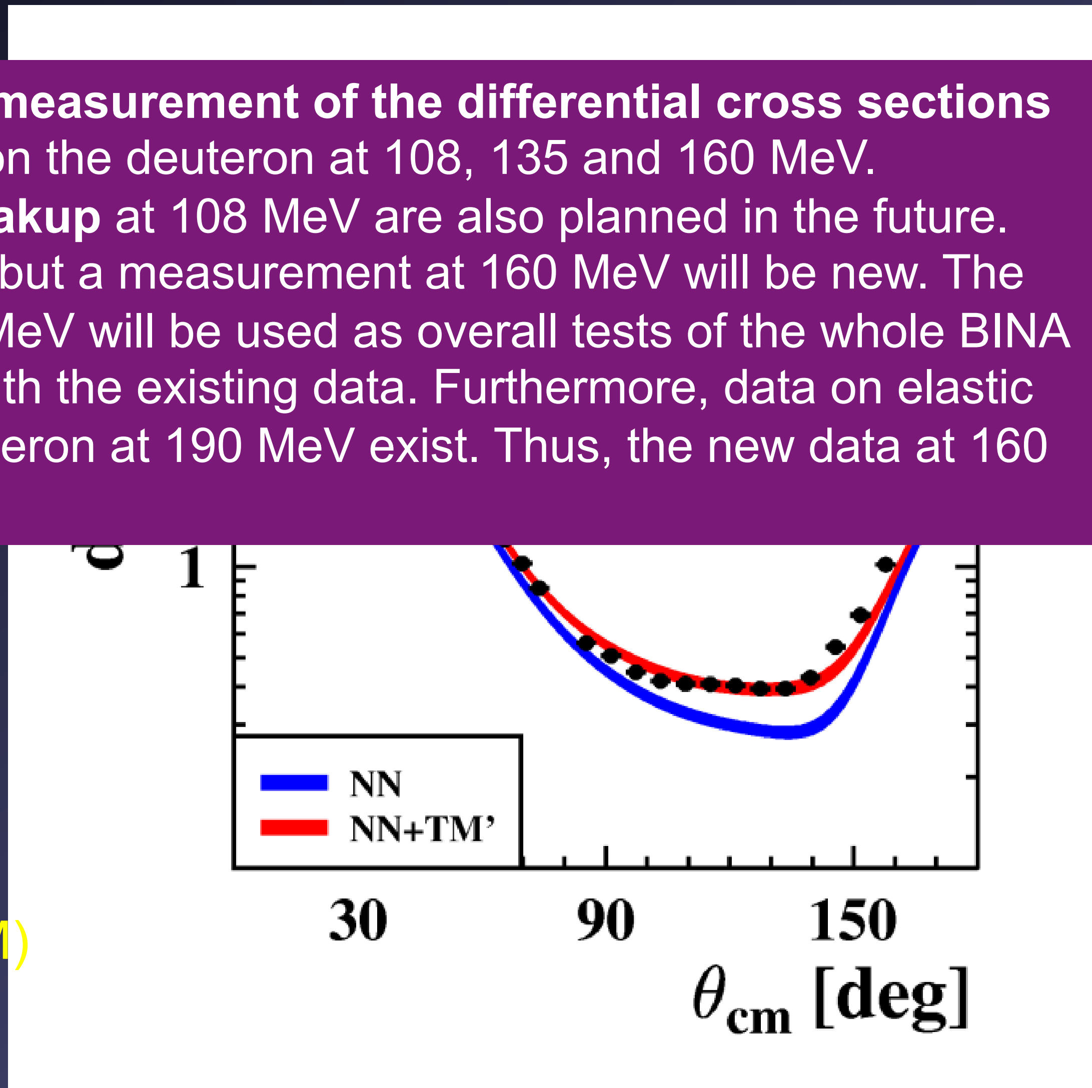
Dynamics of few-nucleon systems with BINA

E. Stephan, A. Kozela, S. Kistryn, N. Kalantar et al.

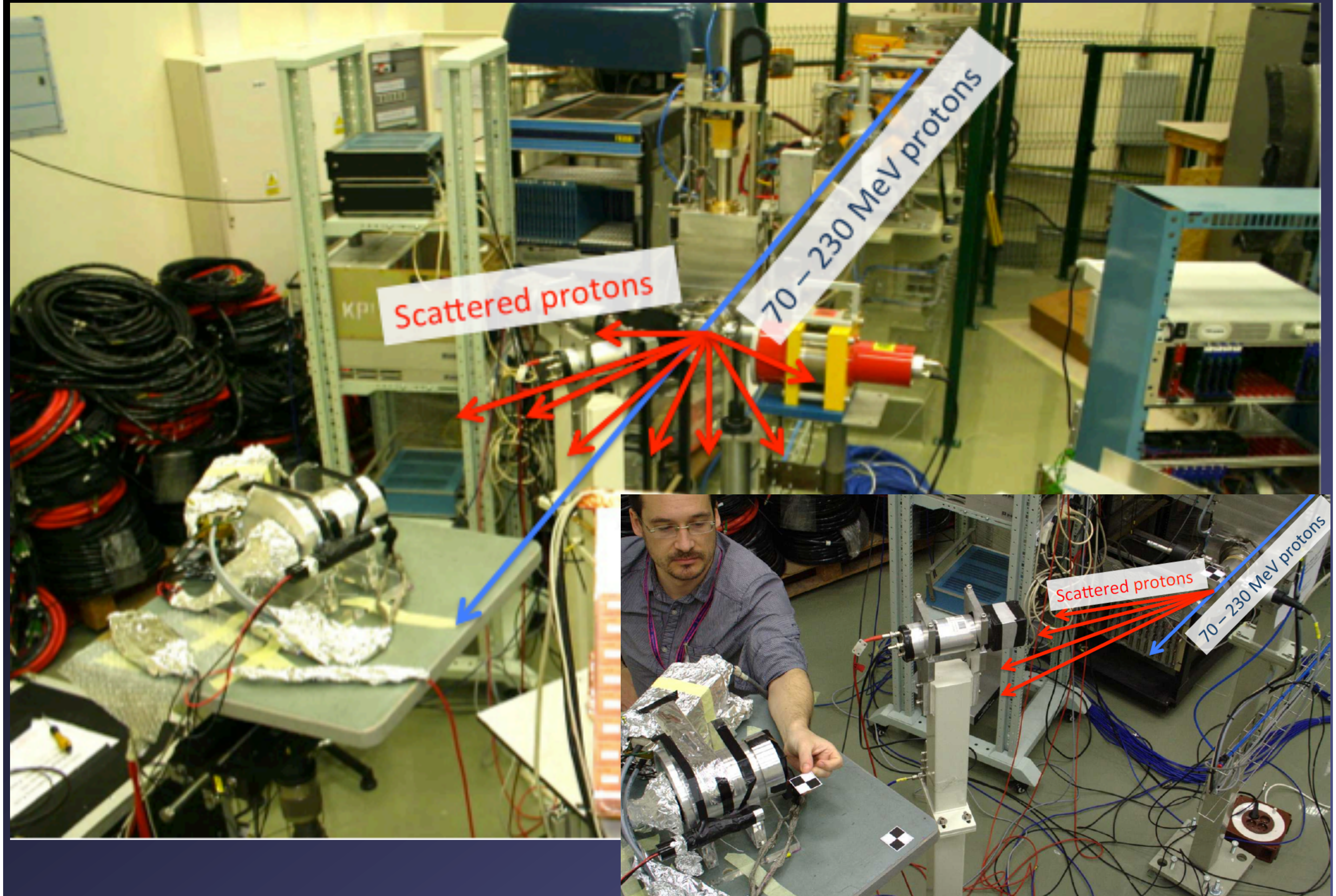
The present proposal aims at **a measurement of the differential cross sections** for elastic scattering of protons on the deuteron at 108, 135 and 160 MeV. Measurements of **deuteron breakup** at 108 MeV are also planned in the future. Data at 108 and 135 MeV exist, but a measurement at 160 MeV will be new. The measurements at 108 and 135 MeV will be used as overall tests of the whole BINA system allowing cross-checks with the existing data. Furthermore, data on elastic scattering of protons on the deuteron at 190 MeV exist. Thus, the new data at 160 MeV will fill the gap.

Realistic potentials NN fail in description of differential cross section for elastic scattering d(p,p)d.

Supplemented with 3NF (TM) perform much better.



Tests of various $LaBr_3$ detectors (CALIFA and PARIS)


Scattered protons
70 – 230 MeV protons
Scattered protons
70 – 230 MeV protons

First paper from the CCB facility!

Nuclear Instruments and Methods in Physics Research A 769 (2015) 105–111

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Nuclear Instruments and Methods in Physics Research A

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Proton response of CEPA4: A novel $LaBr_3(Ce)$–$LaCl_3(Ce)$ phoswich array for high-energy gamma and proton spectroscopy

E. Nácher[a,*], M. Mårtensson[b], O. Tengblad[a], H. Álvarez-Pol[c], M. Bendel[d], D. Cortina-Gil[c], R. Gernhäuser[d], T. Le Bleis[d], A. Maj[e], T. Nilsson[b], A. Perea[a], B. Pietras[c], G. Ribeiro[a], J. Sánchez del Río[a], J. Sánchez Rosado[a], A. Heinz[b], B. Szpak[e], M. Winkel[d], M. Zieblinski[e]

[a] Instituto de Estructura de la Materia, CSIC, E-28006 Madrid, Spain
[b] Chalmers University of Technology, S-41296 Göteborg, Sweden
[c] Universidad de Santiago de Compostela, E-15782, Spain
[d] Technische Universität München, 80333, Germany
[e] Polish Acad. Sci., H Niewodniczanski Inst Nucl Phys, PL-31342 Krakow, Poland

130 MeV protons. These are at the limit of absorption in the first crystal, all energies above will pass through the $LaBr_3$ and enter the $LaCl_3$ crystal. One of such examples are the 150 MeV protons that we can see as a spot in the banana corresponding to all the protons stopped in the second crystal. Finally, it is more difficult to visualize, but we have also included the spot which corresponds to the 220 MeV protons that pass through the entire length of the phoswich unit. We can zoom in Fig. 6 pointing at the 220 MeV spot and change to the three-dimensional representation of Fig. 7. In this way we can have an impression of the ability of the CEPA4 detector combined with the pulse-shape analysis to separate the 220 MeV protons that have passed through the detector from the continuum at lower energies. This implies that, with the appropriate unfolding algorithm, one can reconstruct the original energy of the protons even at the energies that push the Bragg peak out of the volume of the detector. Furthermore, at 220 MeV we still separate the peak from the neighboring energies with a resolution of around 7%, but it gets worse as we increase the energy (see next section).

2.3. *Energy calibration and resolution*

The calibration function which converts the experimental channels (height of the electronic signal) into energy is difficult

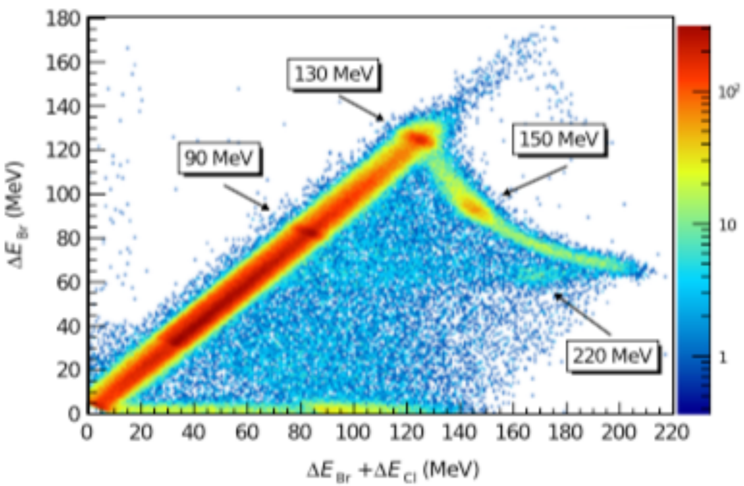


Fig. 6. Two-dimensional $\Delta E-E$ plot for different runs with different proton energies: 90, 130, 150 and 220 MeV. The vertical axis represents the energy deposited in the $LaBr_3$ crystal and the horizontal axis the total energy deposited in the phoswich.

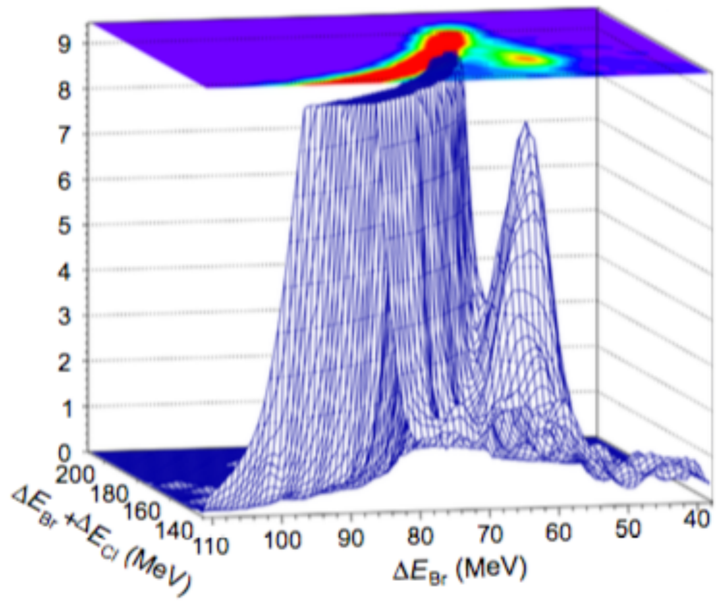


Fig. 7. Same as Fig. 6 in a three-dimensional representation. The graph is zoomed around the spot at 220 MeV and a smoothing has been applied on the data.

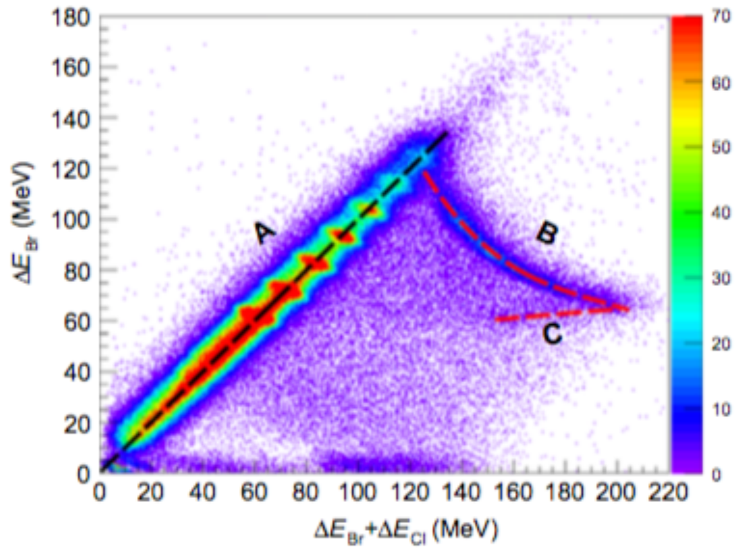
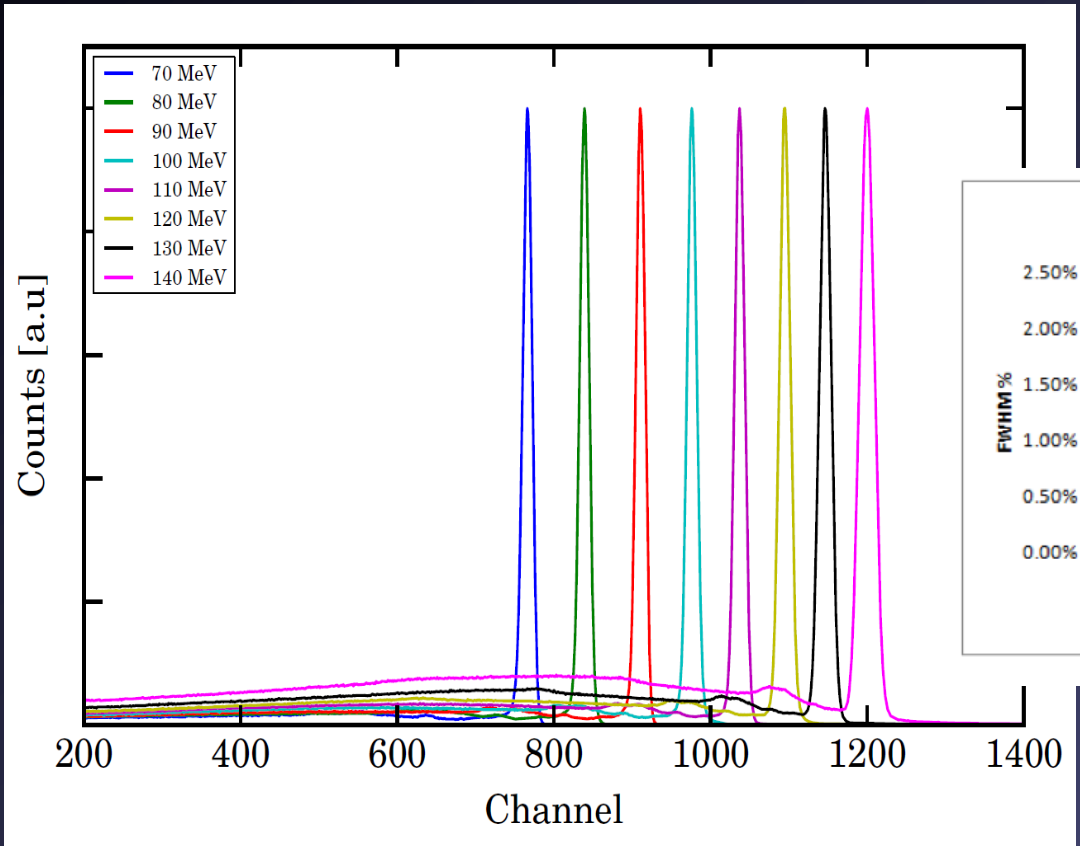
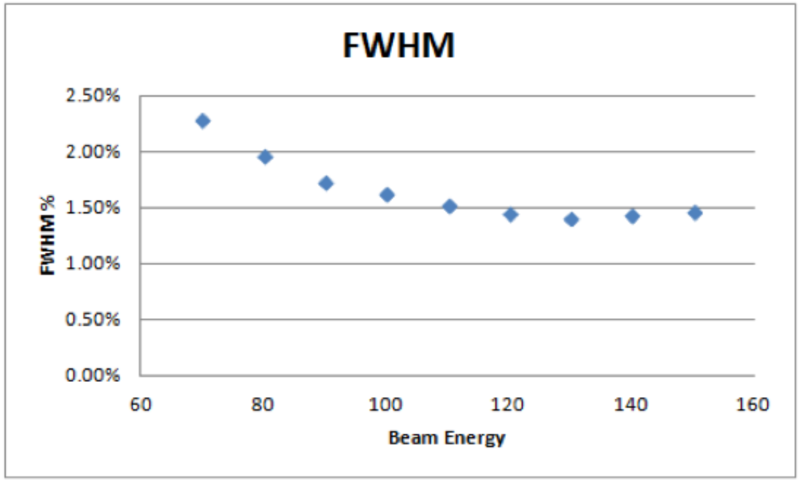


Fig. 8. Two-dimensional $\Delta E-E$ plot for the runs included in the resolution analysis (protons of 70–230 MeV). The 2D histogram has been later projected onto the three lines: A, B and C for the determination of the energy resolution (see the text).

First proton spectra from the Ti(p,p') reaction measured at CCB with a $LaBr_3$ detector





Spectra of protons at different beam energies measured with a 2" x 2" x 2" $LaBr_3$:Ce crystal at 5 deg. relatively to the beam axis. The spectra are normalized to have the same height of a proton peak.

National Laboratory of Cyclotrons

Warsaw / Kraków

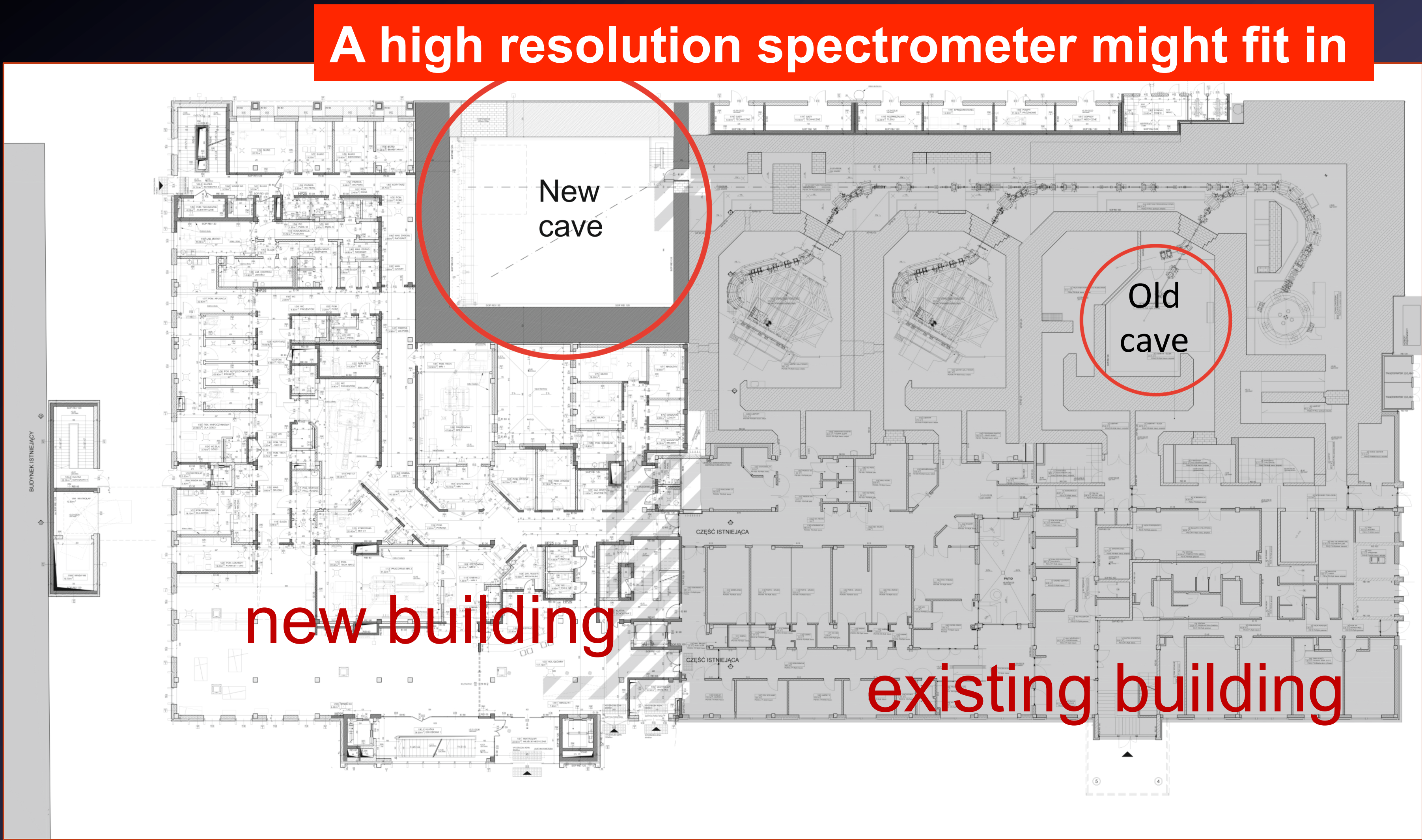
Ongoing efforts to include NLC (CCB at IFJ PAN and HIL at Warsaw University) in the HORISON2020 ENSAR project as Transnational Access Facility

The nuclear physics research programme of NLC aims at obtaining high quality data on nuclear properties at and around the valley of stability. Therefore, it is complementary to the programmes of large-scale European RIs, which are concentrated on the physics of nuclei very far from the stability line, often at the limits of detection.

The investigations carried out in Warsaw and Kraków are also in many aspects complementary - at CCB high-energy proton beam is available while at SLCJ beams of heavier nuclei from boron to argon can be accelerated.

Possible future developments

New experimental hall at CCB - project



New experimental hall at CCB - project

Conclusions

- New facility CCB with proton beam (70-230 MeV), both for hadron therapy and basic research in nuclear physics becomes operational in Krakow
- NLC consortium (HIL Warsaw + CCB Krakow) might be the TNA facility in the H2020 EC ENSAR2 program, providing interesting research opportunities
- We hope to learn a lot from the collaboration with RCNP
- You are welcome to submit a proposal and come to Krakow

Thanks to:
Marek Jezabek, Pawel Olko,
Bogdan Fornal, Maria Kmiecik, Adam Kozela, Basia Wasilewska, Witek Meczynski, Mirek Zieblinski, Piotr Bednarczyk, Jerzy Lukasik,
Angela Bracco, Sergio Brambilla, Franco Camera, Fabio Crespi ….
and many others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