CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

6th DITANET Topical Workshop on Particle Detection Techniques

The gamma proton calorimeter for R^3B

Grupo de Física Nuclear Experimental IEM

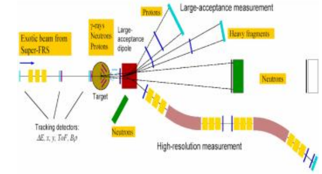
O. Tengblad IEM-CSIC

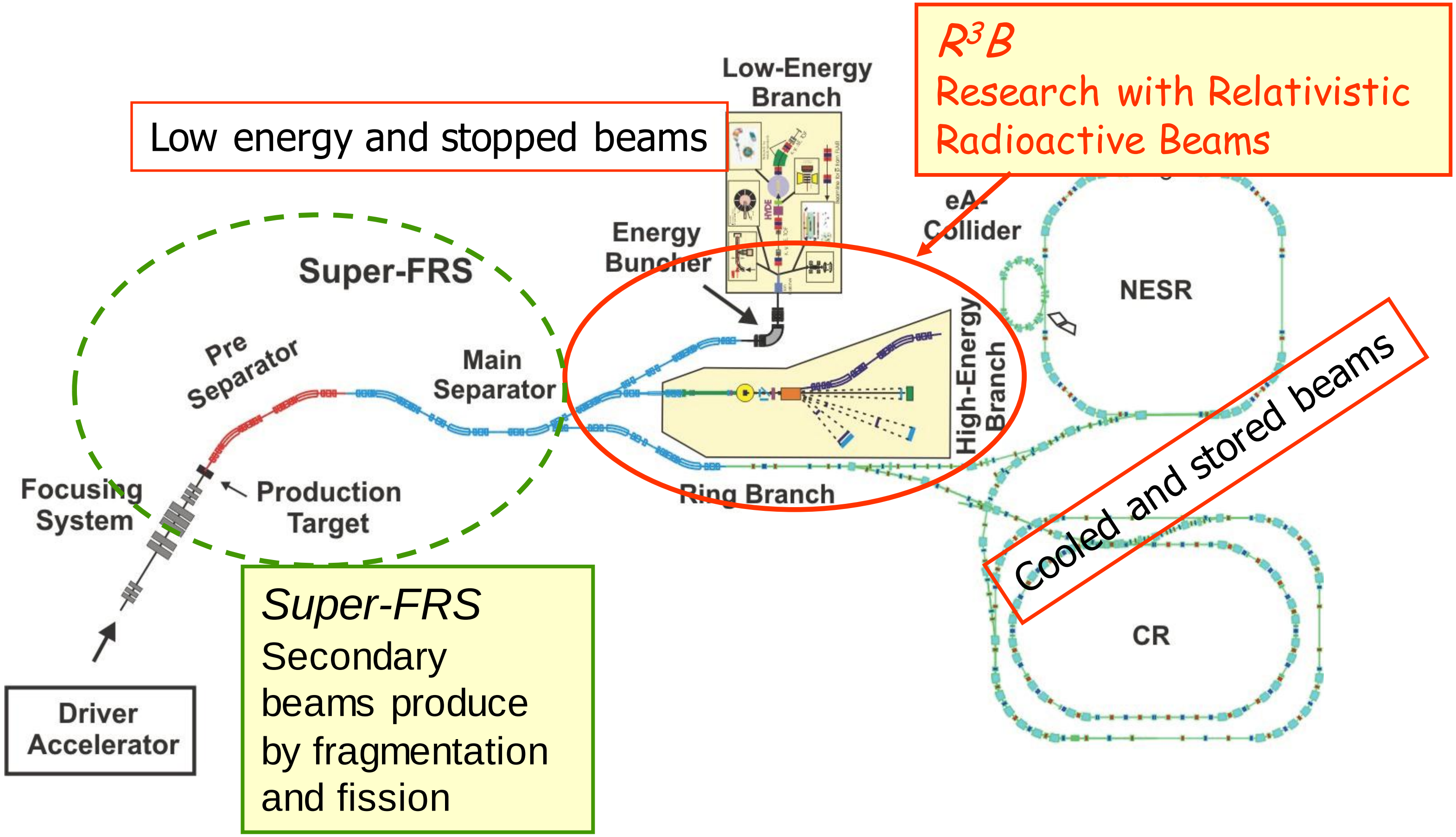
For the CALIFA WG and the R3B collaboration

Instituto de Estructura de la Materia, CSIC, E-28006 Madrid, Spain

- General introduction to R3B & CALIFA
- CALIFA
- End cap & Phoswich concept
- Simulations for Phoswich

NUSTAR – a facility for NUclear STructure & Astrophysis Research





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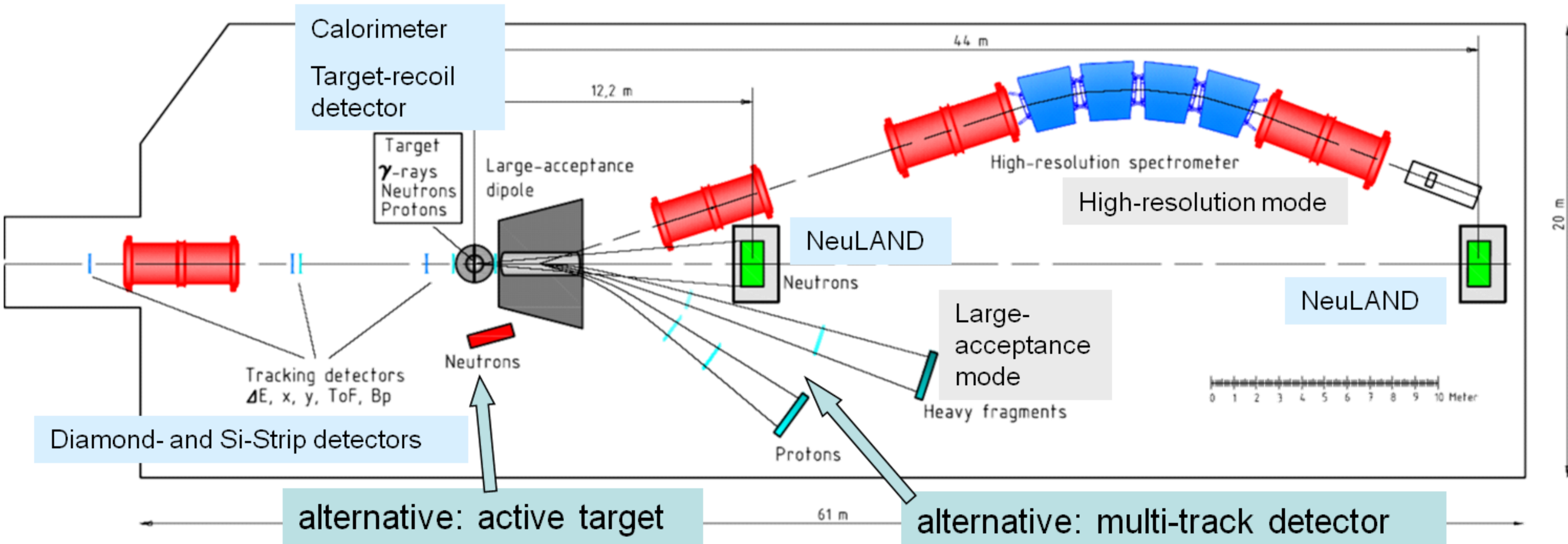
R^{3}B: Reactions with Relativistic Radioactive Beams



Kinematically complete measurement of reactions with high-energy secondary beams

- **Nuclear Astrophysics**
- **Structure of exotic nuclei**
- **Neutron-rich matter**

•A universal fixed-target experiment for complete inverse-kinematics reactions with relativistic RIBs (~300 – 1500 MeV/u),

•Experiments with the most exotic (<1 ion/s) and short-lived nuclei - exploring the isospin frontier at and beyond the drip-lines –

•Concept built on existing ALADIN-LAND experiment at GSI

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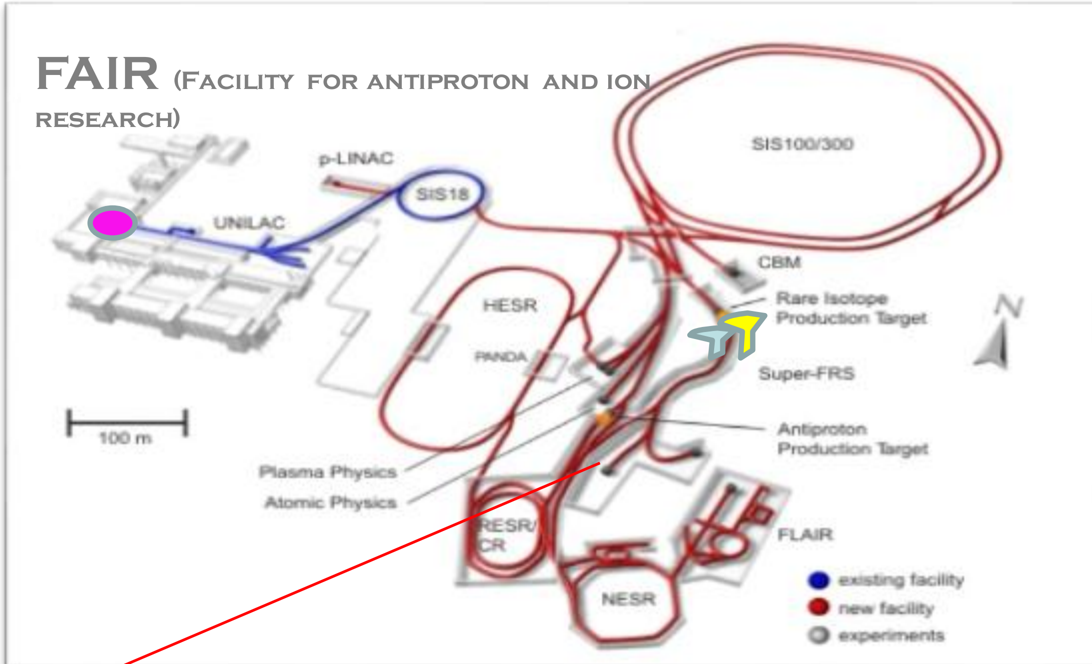
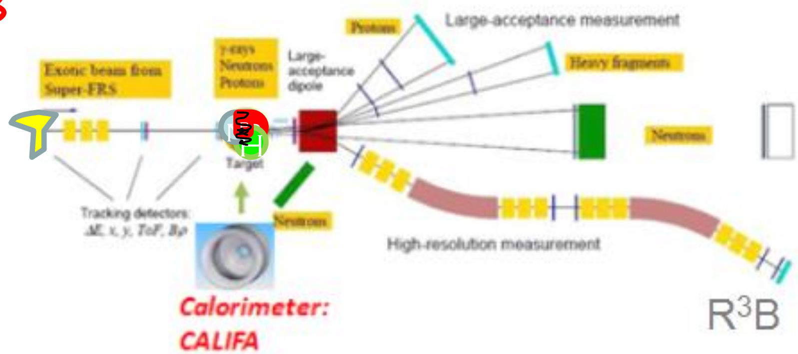
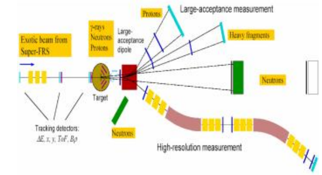
R3B

How does it work



R3B





1. Accelerated beam impact on Production Target

2. Products are separated in FRS

3. Separated isotopes directed to experiment

4. Isotope of interest impact on Reaction Target

5. Reaction fragments and gammas are detected

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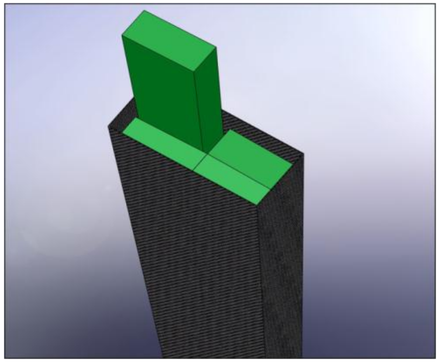
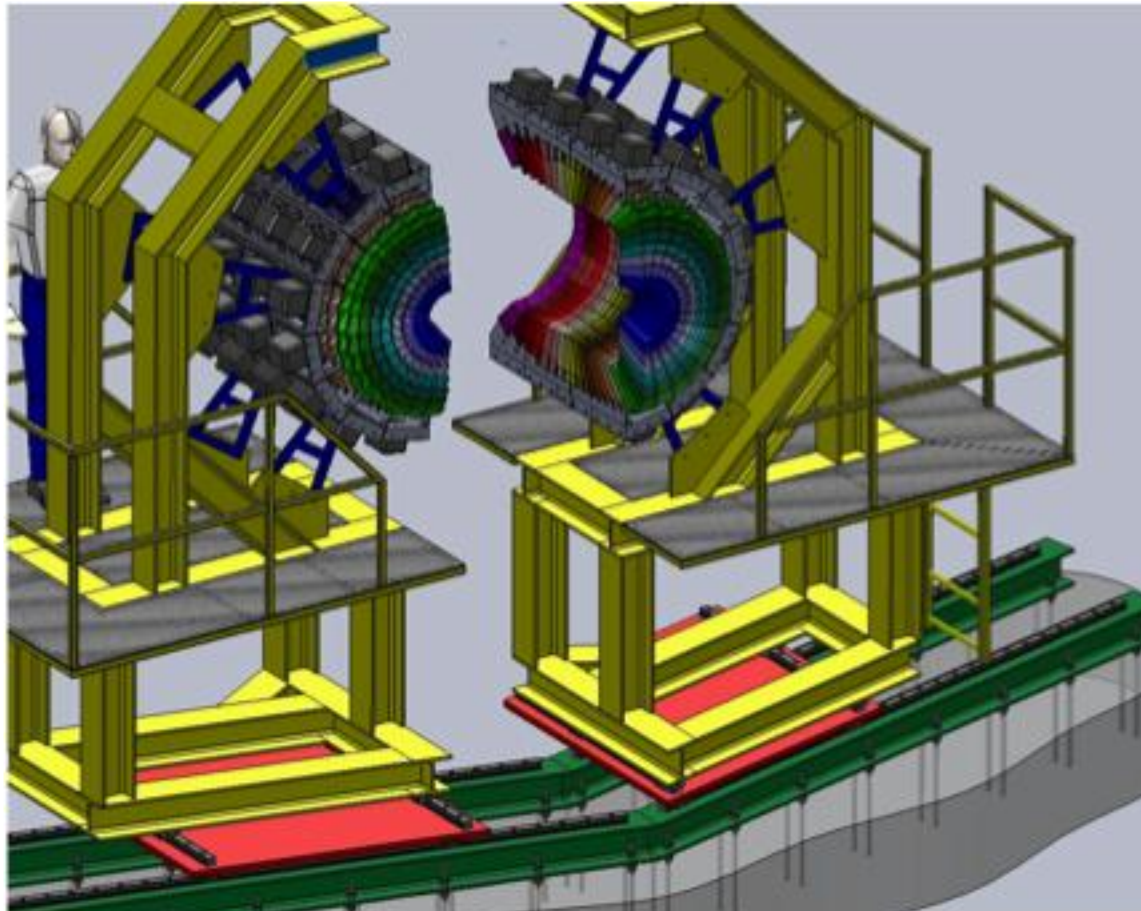
CALIFA





GENP
Grupo Experimental de Núcleos y Partículas

CIMA
Universidad de Vigo

IEM CSIC
Grupo de Física Nuclear Experimental
IEM

Avancez 1829

Technische Universität München

Lund University

TU Darmstadt

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CALIFA

- **high-resolution spectrometer, relatively low-energy γ-rays (up to 2 MeV), consequently with low multiplicity (2-3). The energy resolution will be in this case the most critical parameter of CALIFA. This value has been set to be of E/E < 6% for 1 MeV , which allows to distinguish most of the simple gamma cascades that come from the de-excitation of light exotic nuclei.**

  knock-out reactions employing light, radioactive beams. → Segmented

- **calorimeter, very energetic rays (up to 10 MeV) and associated with fragmented decays (high-multiplicity events). In this case the key parameters will be its Total absorption (intrinsic photopeak efficiency), sum energy and multiplicities. A typical reaction that will profit from**

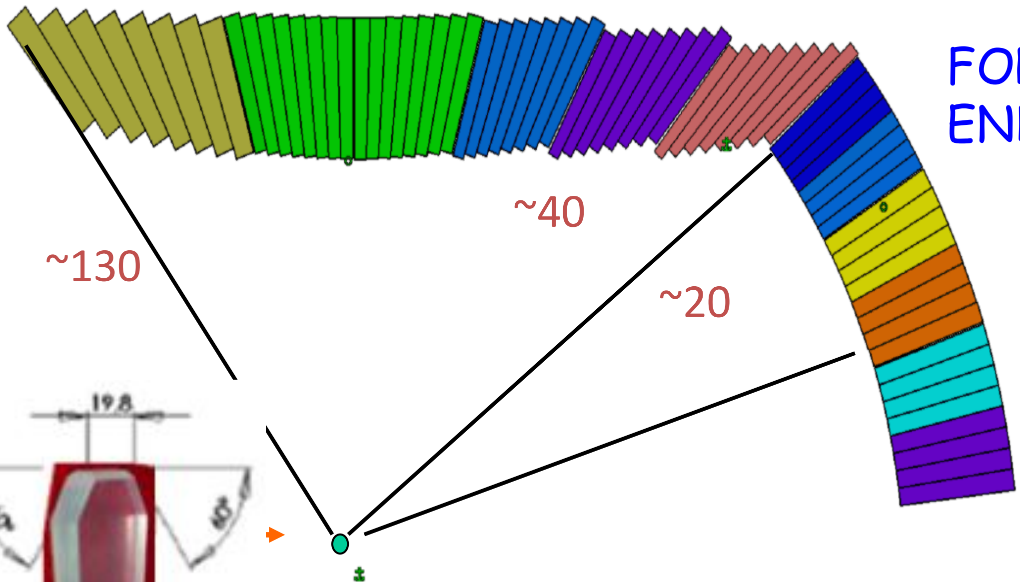
  pygmy (or giant)-resonance decays. → addback little dead material

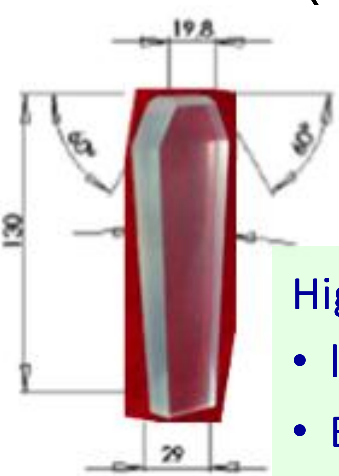
- **hybrid detector simultaneously good calorimetric properties together with high-resolution. highly energetic light charged particles (protons up to 300 MeV)**

  quasi-free scattering (p,2p),(p,pn)…. → good energy resolution + huge dynamic range.

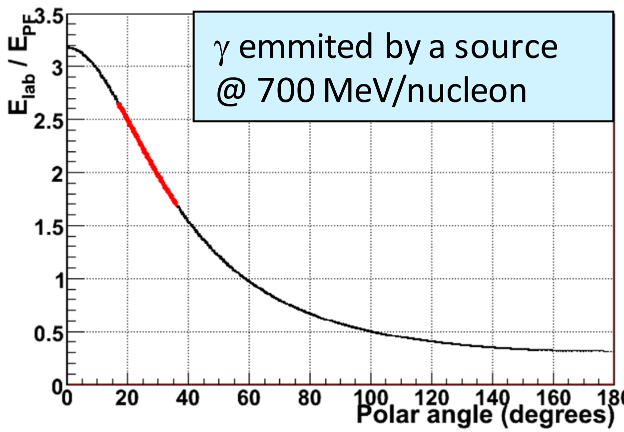
Design of CALIFA

Kinematic considerations





Detect with good energy resolution & efficiency
γ < 30 MeV
p < 300 MeV



High energy reaction → forward emission

- leave backward angles >130º open for access (liquid target/electronics)
- BARREL 40 – 130º → CsI(Tl) + LAAPD
- FORWARD ENDCAP 6- 40º → improved angel and energy resolution, thinner/longer crystals?

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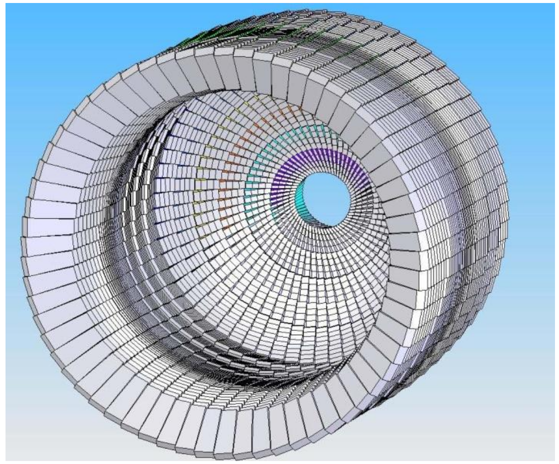
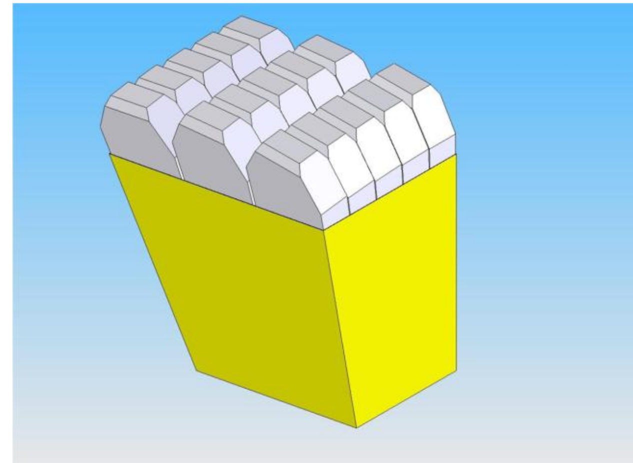
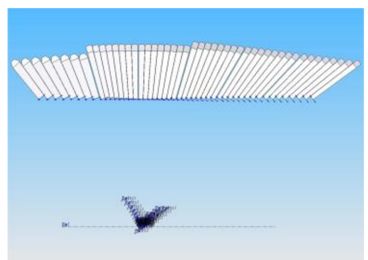
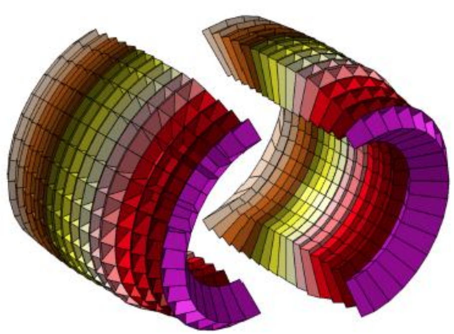
Univ. Santiago de Compostela

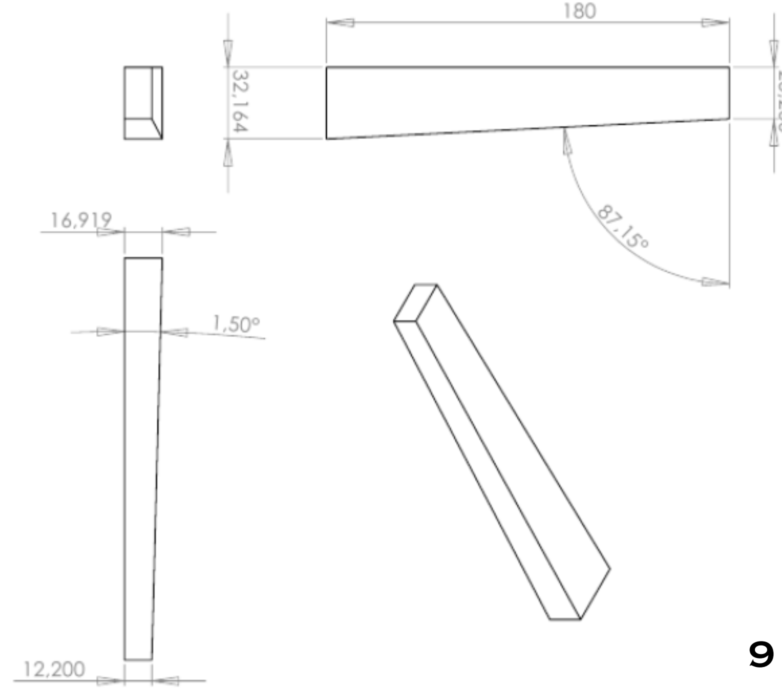
Design/Simulations of barrel





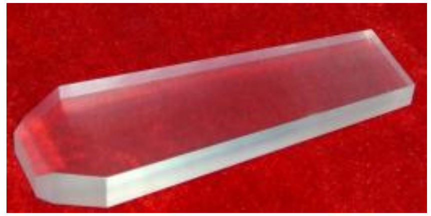


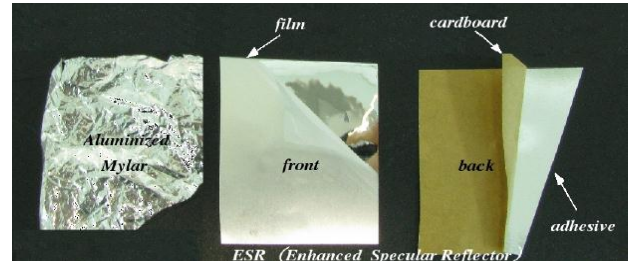




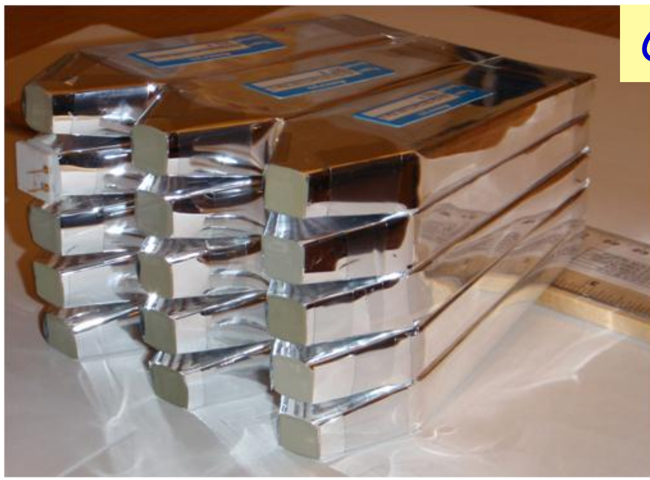
Inner radius	30 cm
Numb. of crystals	1952
Diff. crystal geometries	31
Crystal weight (CsI(Tl))	≈ 2000 kg

Crystals have been tested extensively

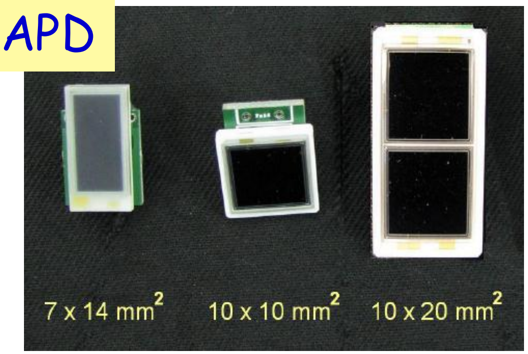


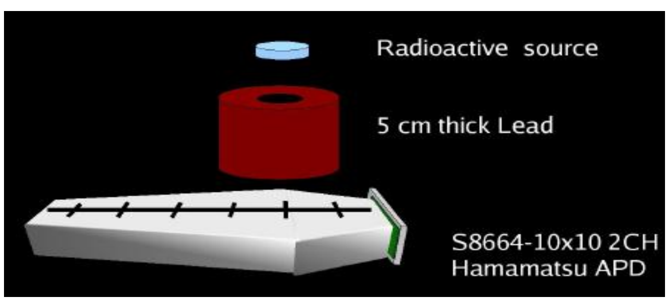


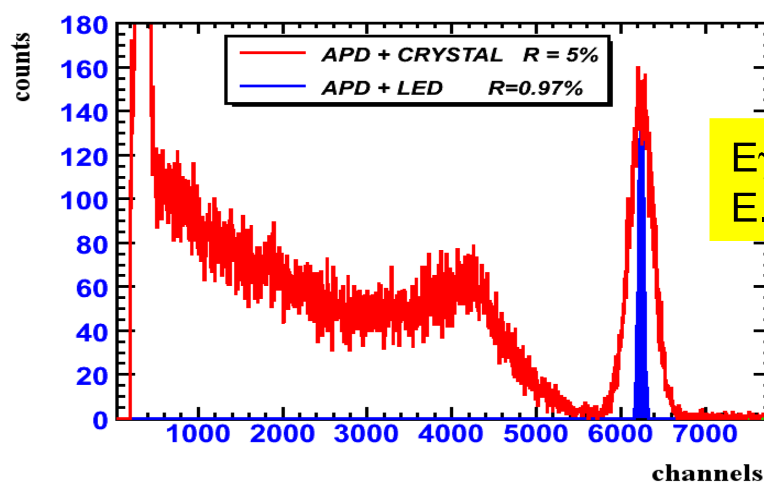
CsI(Tl)



APD





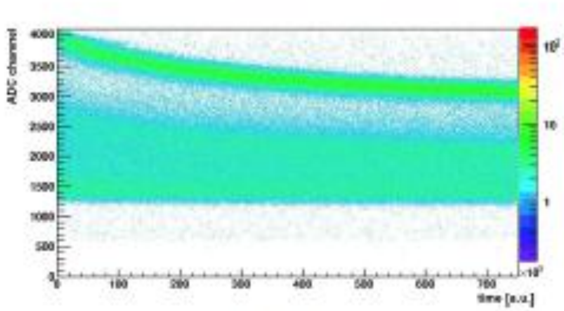


Eγ=662 KeV
E.R. 4.4%

Readout: Voltage stabilization to ambient temp

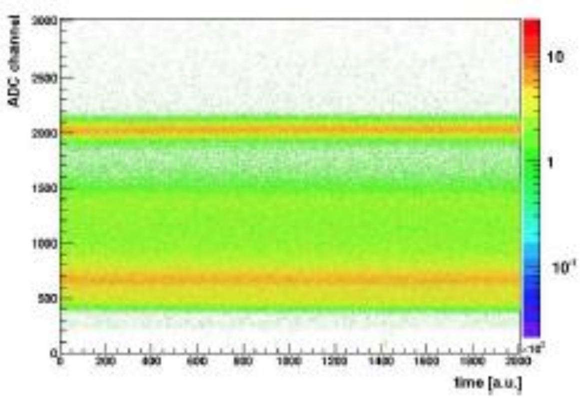
Spectrum of a 137Cs source measured with a CsI(Tl)-crystal and read out by an Hamamatsu S8664-1010 LAAPD.

$$\frac{1}{G}\frac{dG}{dT} = -2.95\frac{\%}{°C} \qquad \frac{1}{G}\frac{dG}{dU} = 2.5\frac{\%}{V}. \qquad \frac{dU}{dT} = 1.18\frac{V}{°C}$$



(a)

Gain gradient due to continuous heating
of the LAAPD from 11.3C to 22.7C

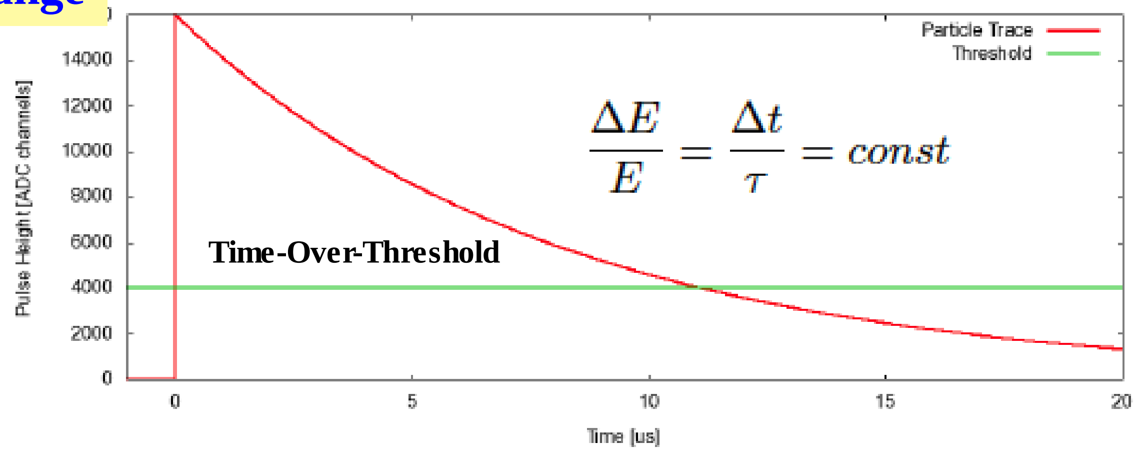


Temperature regulated
in the range of 6C to 24C with a

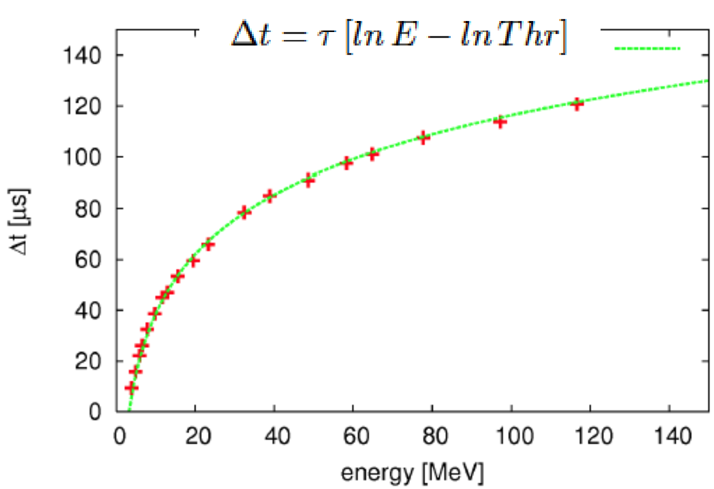
Energy determination via Time-Over-Threshold measurements

Huge dynamic range

$E_\gamma <$ 30MeV
$E_p <$ 300MeV



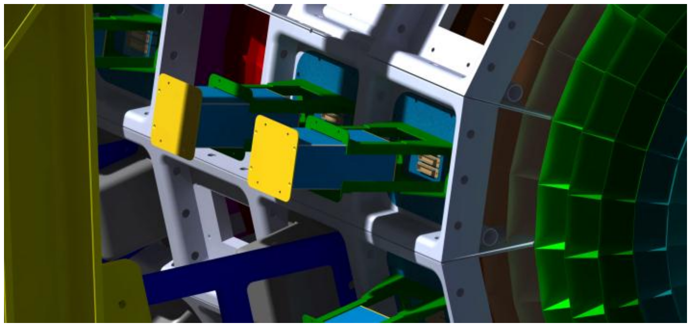
Basic concept of Time-Over-Threshold measurements with an ideal signal trace (red): The time when the input signal exceeds a certain threshold (green) to the point in time, until it returns below, is measured.

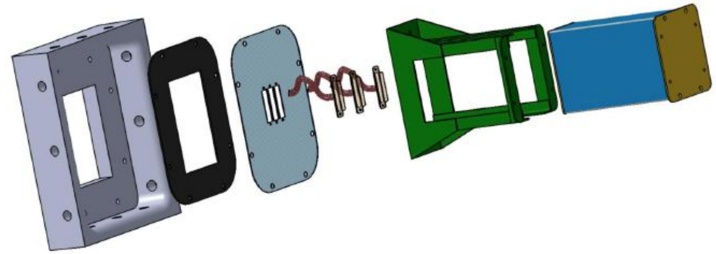


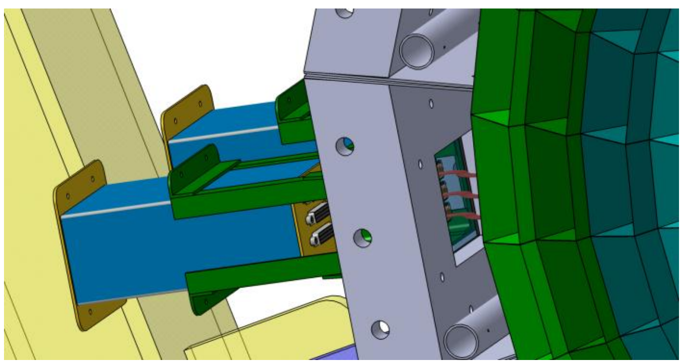
For an ideal exponential input signal the dependence on the energy is logarithmic
(Thr is the threshold value and τ the preamplifier decay time constant.)

Pulser measurements up to an energy of 120MeV confirm the logarithmic behaviour also for real preamplifier signals

PreAmp solution





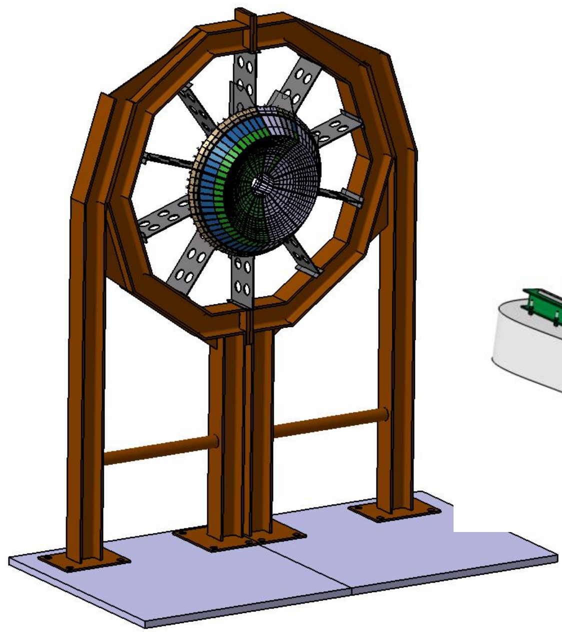


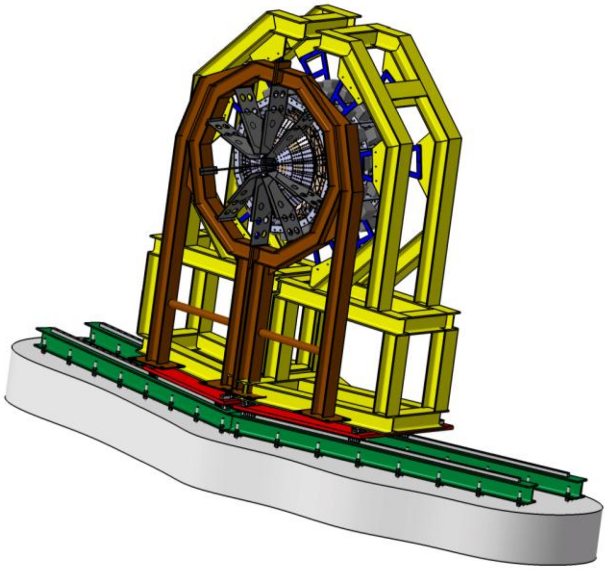
MPRB-16 **16 channel charge sensitive preamplifier with integrated bias voltage generators.**

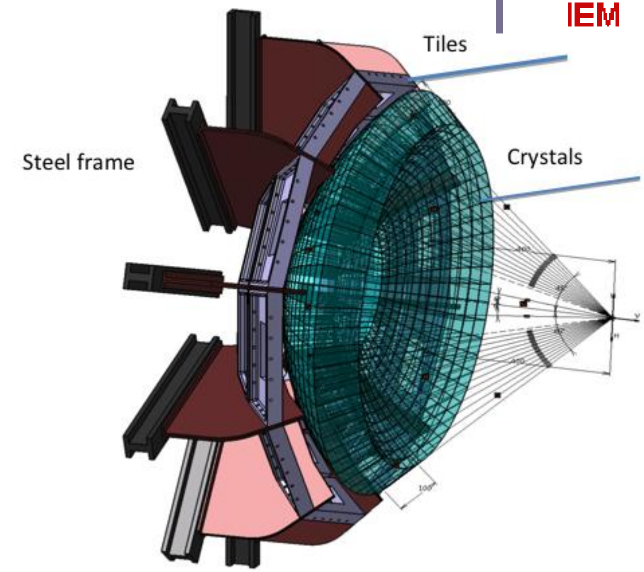
- Remote controllable via mesytec control bus
- **Voltages individually for each channel in 100 mV steps, up to 600 V.**
- Temperature sensor to compensate the APD gain drift with temperature by adapting the bias voltage with temperature.

Forward EndCap
Possible solution
ΔE-E telescope?

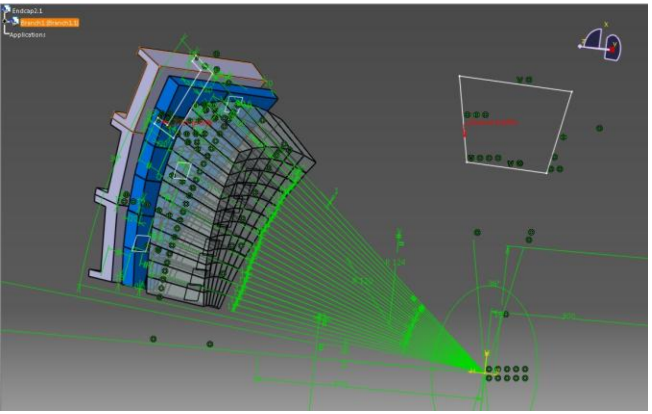
Forward EndCap Possible solution

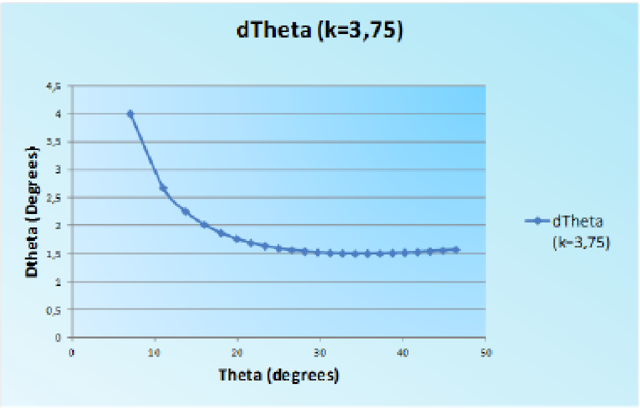


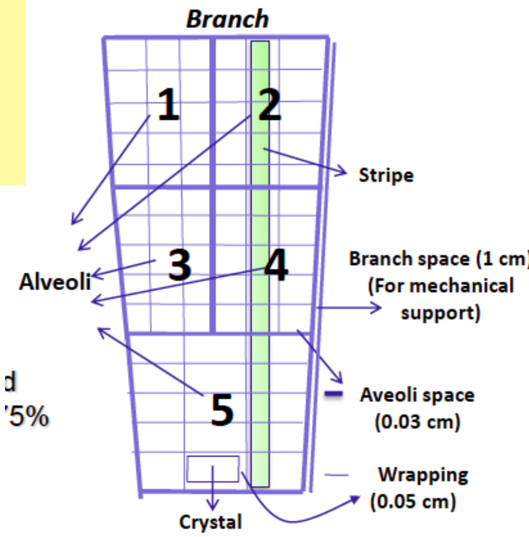




750 crystals: 5 alveoli of 15 crystals each, 10 branches of 75 crystals, 15 rings (from 1-5: 30 crystals, from 5-15: 60 crystals







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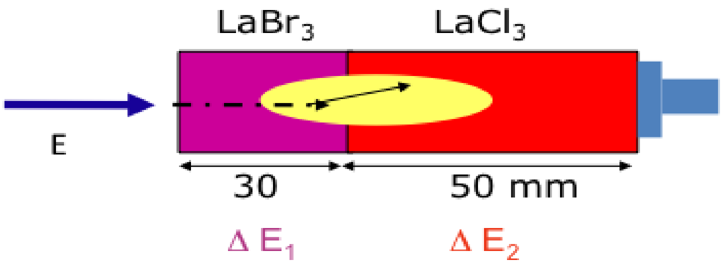
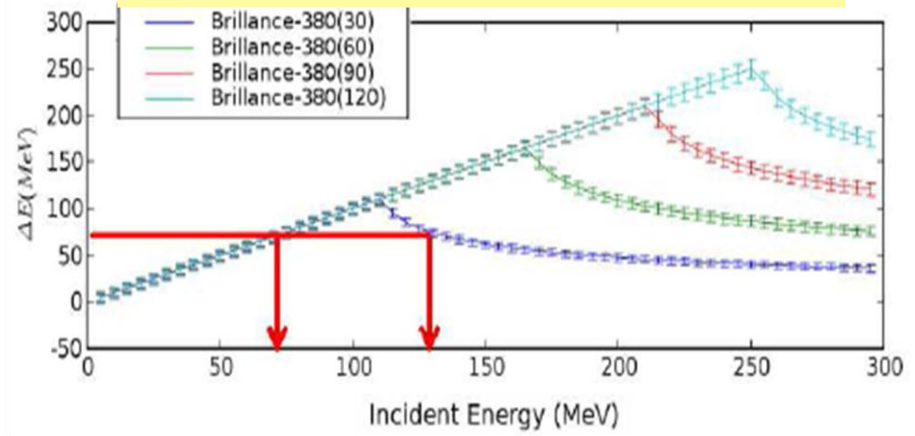
Why Phoswich?

$E \rightarrow \Delta E_1 + \sigma(\Delta E_1) + \Delta E_2 + \sigma(\Delta E_2)$

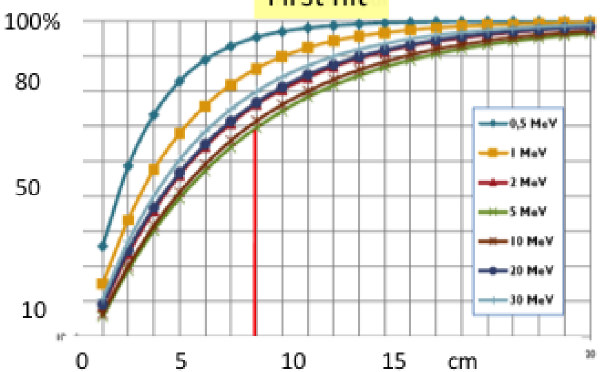




Question to be answered:

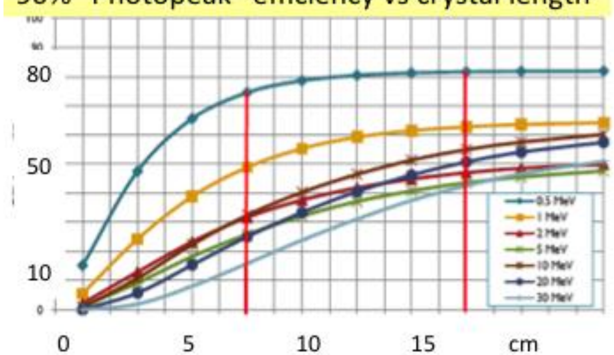
- Depth of first interaction
- Depth @ 90% incident energy absorbed
- How many neighbouring crystals are being hit?

First hit



@7 cm 70 % of incident beam is detected

90% "Photopeak" efficiency vs crystal length



>15 cm has NO influence on detection efficiency

Protons:

Using two ΔE-detectors one can determine the full proton energy with a resolution of <5%.

Gammas:

Second detector placed to solve the ambiguity on the signal

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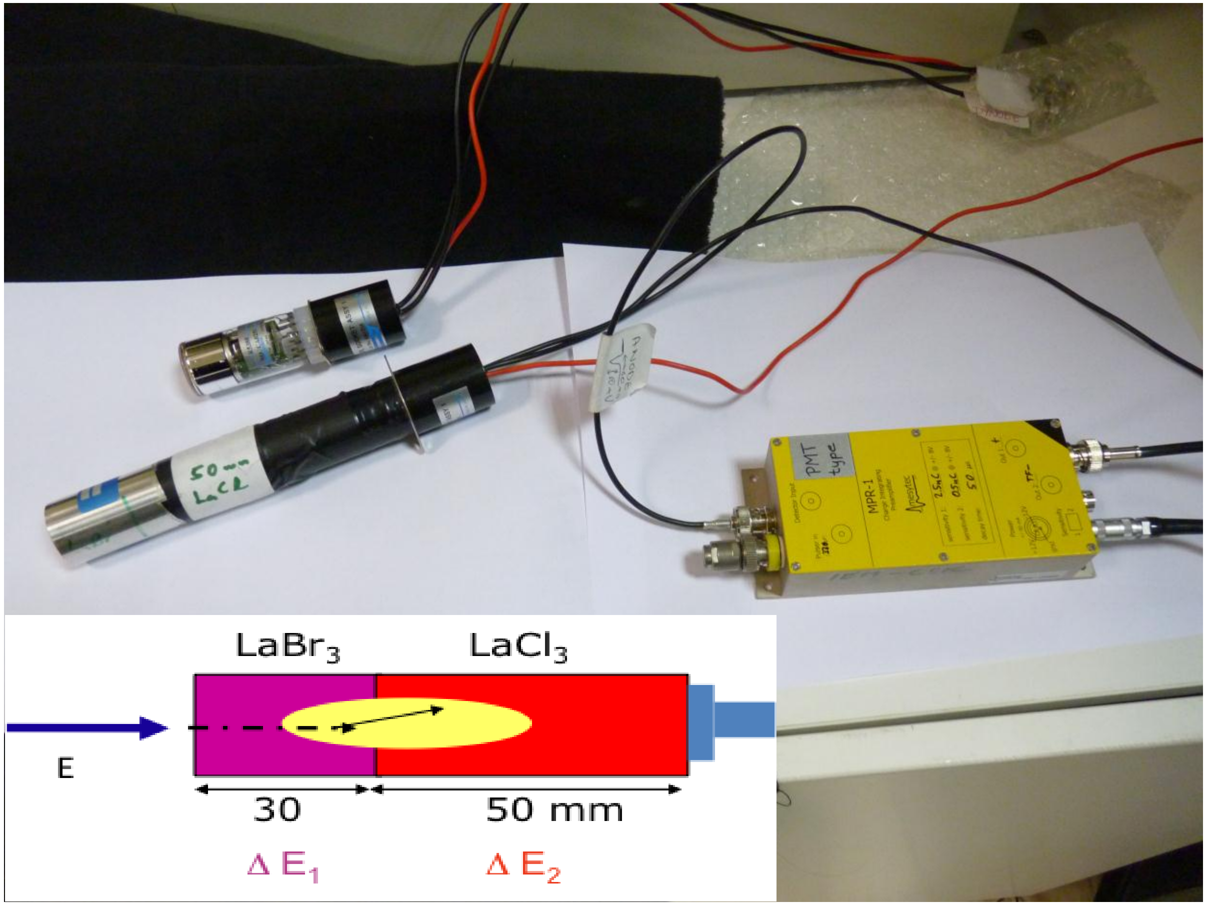
Laboratory tests with 1:st prototype

Phoswich: SaintGobain
$LaBr_3(Ce)+LaCl_3(Ce)$
Φ20mm x (30+50)mm^2

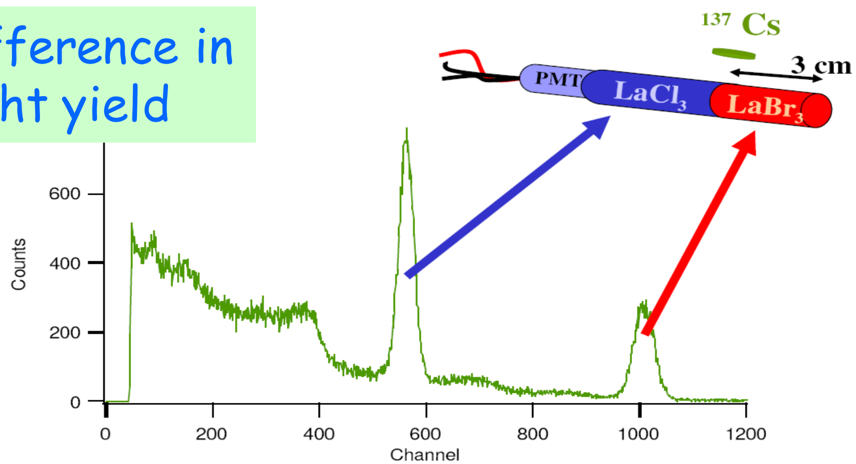
PM-tube: Hamamatsu
R5380 6 dynodes
300-650 nm

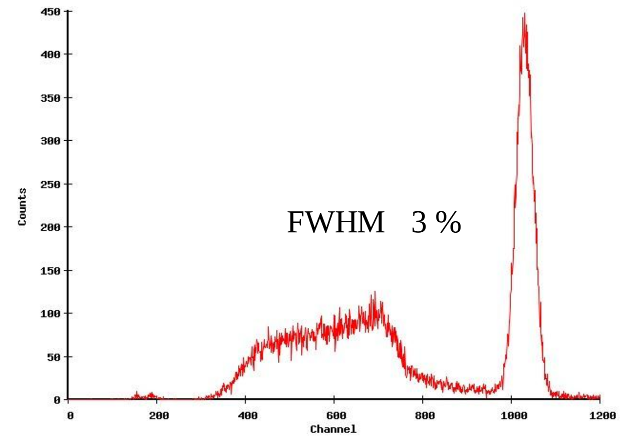
PA: Mesytec MPR1-PMT



Phoswich: 1st results → it works

Difference in Light yield

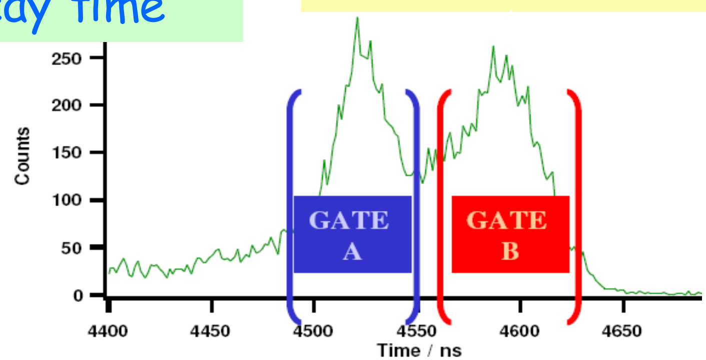




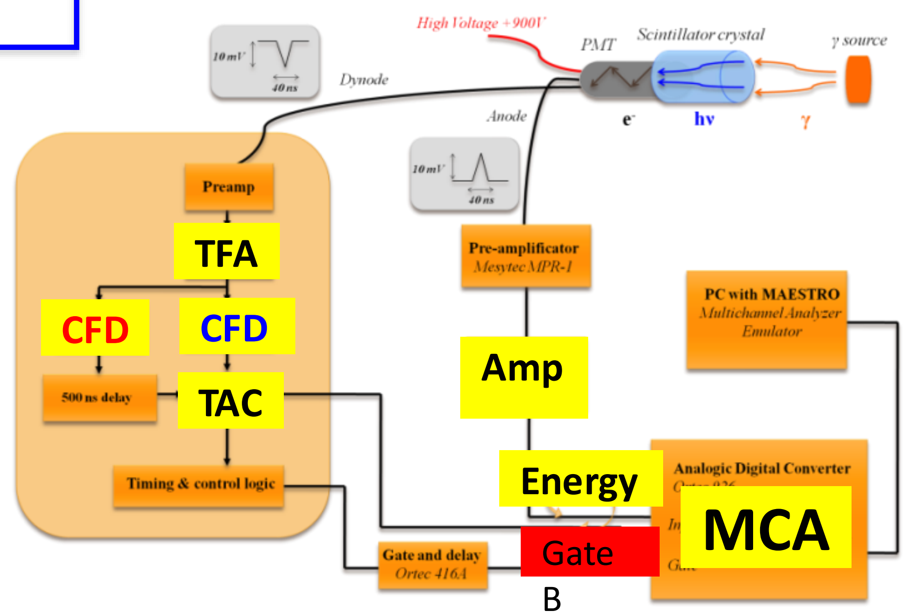
ENERGY SPECTRUM WITH **GATE B**

Light yield (photons/keV γ)		Decay time (ns)
63	$LaBr_3$	16
49	$LaCl_3$	28

Difference in Decay time



PHOSWICH TEMPORAL SPECTRUM



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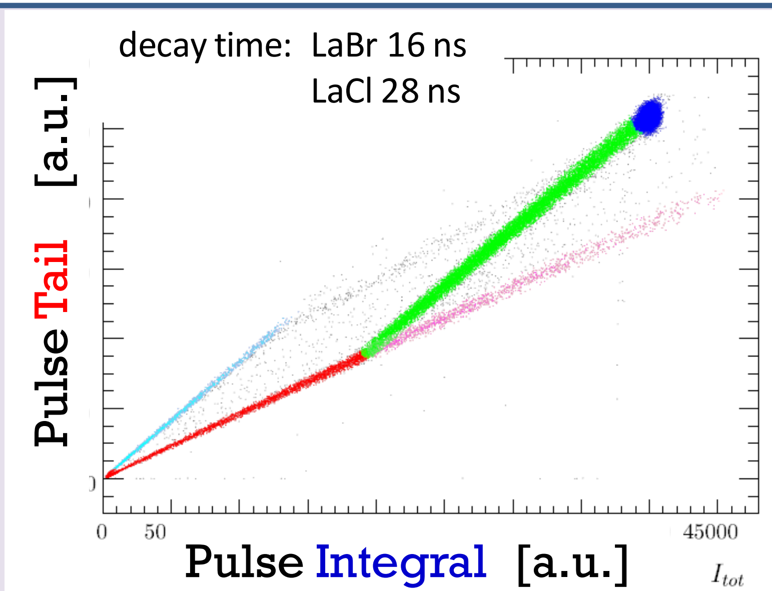
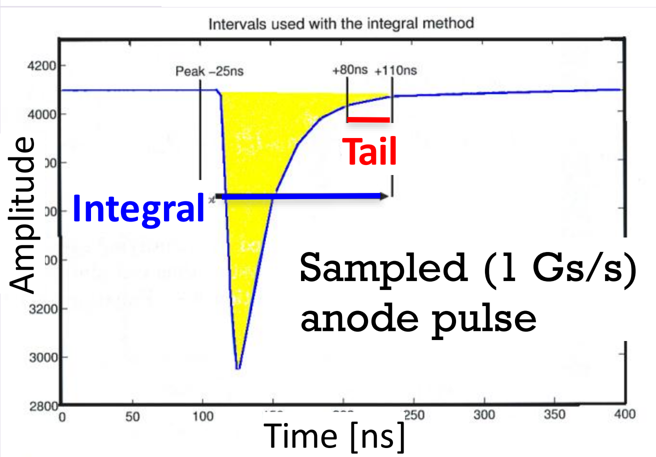
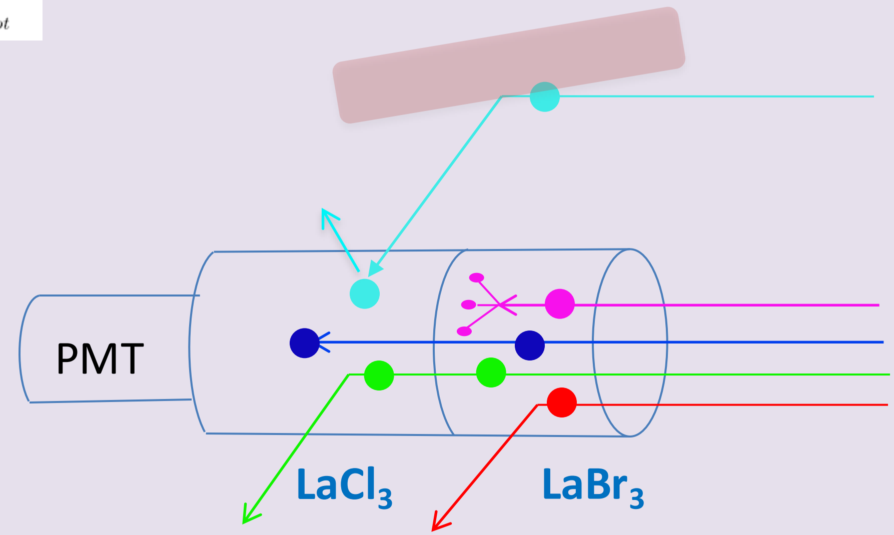
Phoswich detector response to 150 & 180 MeV protons @ The Swedberg Lab. Uppsala



- ❑Proton slowed down in the two crystals
- ❑Proton escaping leaving part of energy
- ❑Proton scattered out from LaBr
- ❑Proton stopped in 1st crystal
- ❑Proton entered from the side to 2nd crystal
- ❑Pile up & noise





PMT + digital readout

Digital: Anode → Sampling ADC 1 Gs/s MATACQ32 from M2J Saclay → off-line PSA
Analog: Dynode → Mesytec MPR1-PMT → Mesytec STM-16 → Caen V785 ADC

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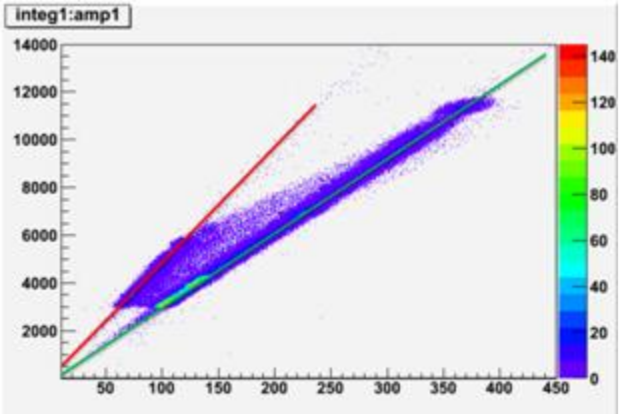
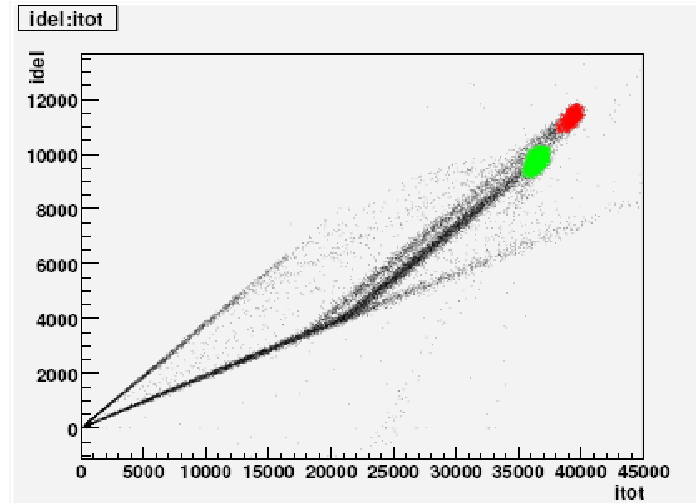
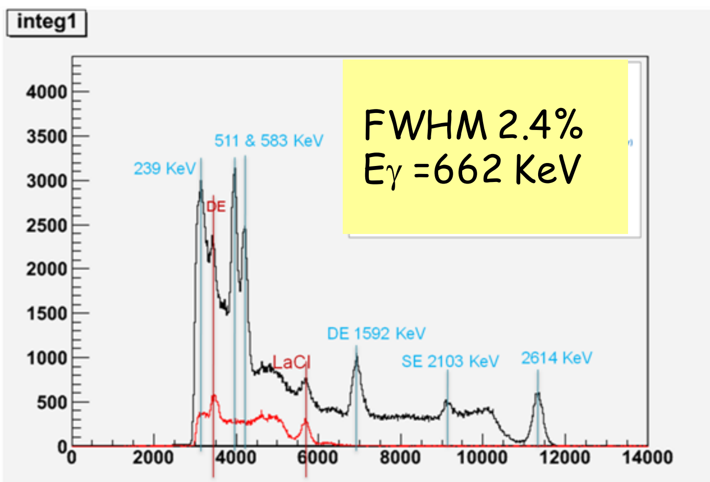
Phoswich response to gammas and protons

Huge dynamic range 200 KeV γ 200 MeV p
the same electronic settings and PM voltage

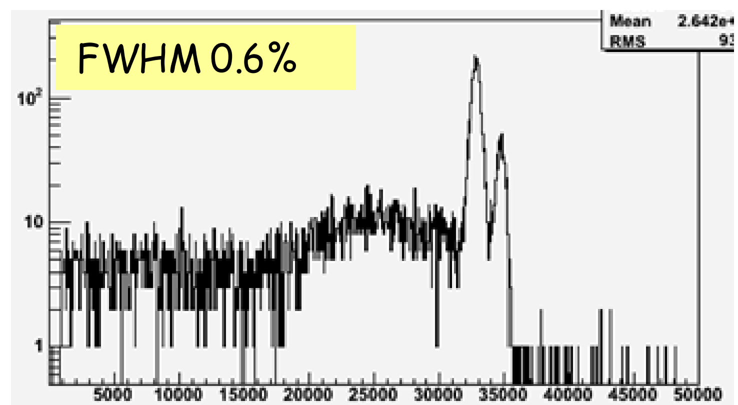




228Th gamma source
Eγ = 200 -2600 KeV



150 + 180 MeV Protons



Simulation of obtained data

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GEANT4 simulartion of the Experiment at TSL

- Proton energy: 180 MeV before leaving the beam-pipe,
  after the Al cylinder with hole → ≈150 & 180 MeV
- Detector $LaBr_3$(Ce) + $LaCl_3$(Ce) cylinder: 2cm x (3 + 5) cm^2
- Physics list:
  Low Energy EM processes (Livermore) for gamma-rays, electrons and positrons. Bertini Intranuclear Cascade for hadrons.

Geant 4 simulations by: E. Nacher

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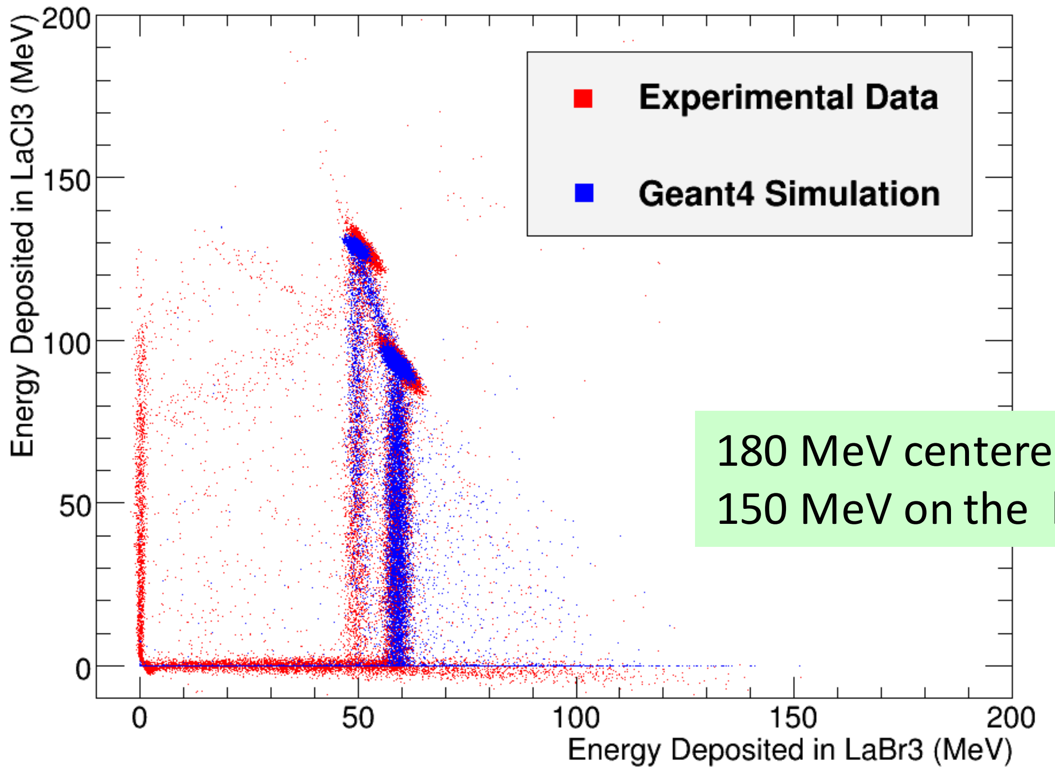
Results

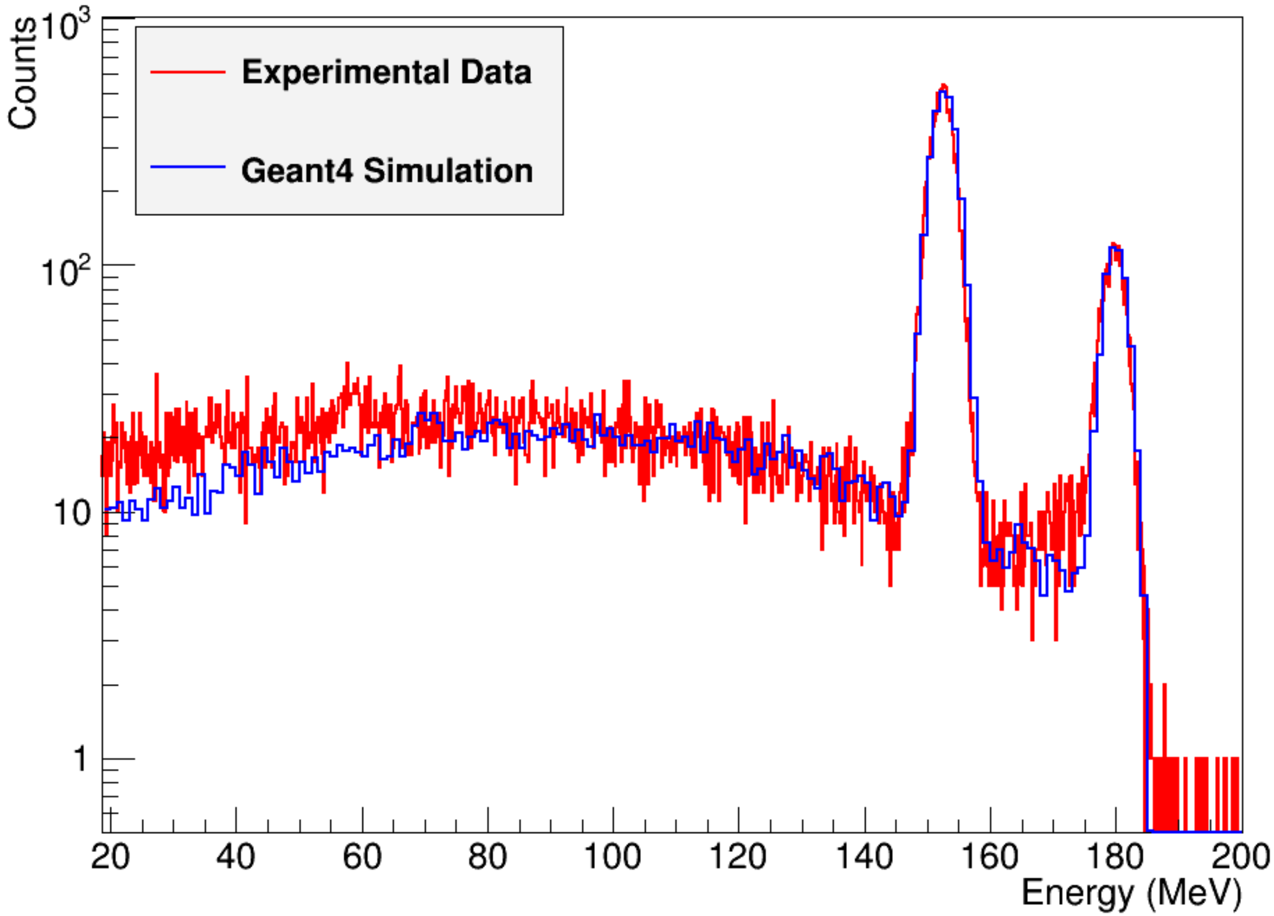
- Energy deposited in $LaCl_3$ vs Energy deposited in $LaBr_3$.
- Data from off-line Pulse Shape Analysis.
- Experimental **data** overlayed with Geant4 **simulation**.



180 MeV centered
150 MeV on the boarder → tail

150 & 180 MeV protons

- Energy spectrum adding up the total energy deposited in both crystals Experiment in RED, Geant4 in BLUE



Simulations: Design of Next Prototype

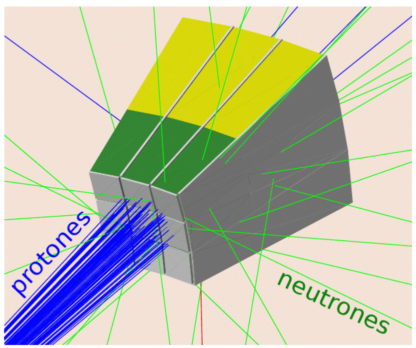
Protons in prototype "CEPA"

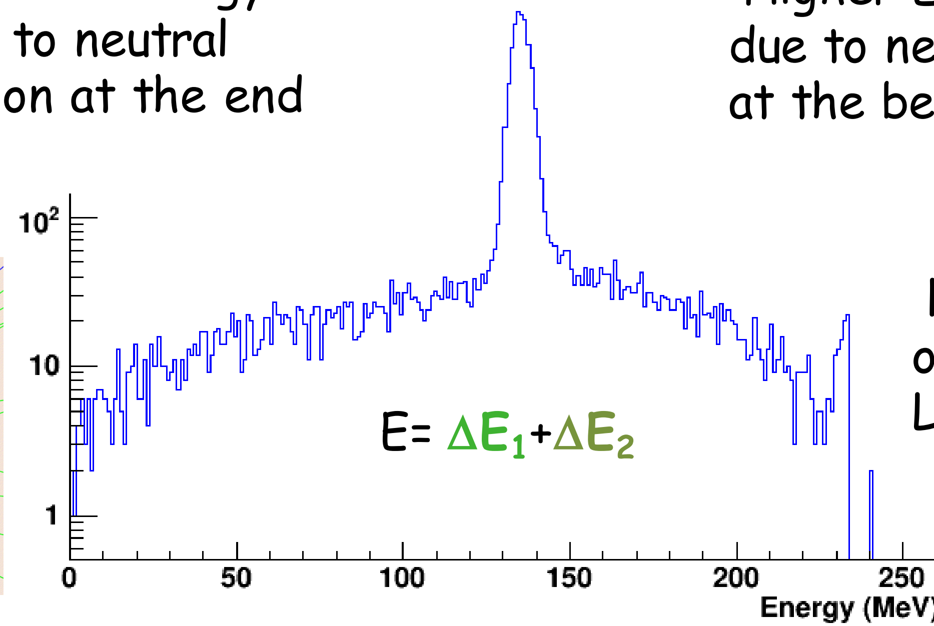
- Energy spectrum for E=240 MeV protons → $\Sigma\,(\Delta E_1 + \Delta E_2)$

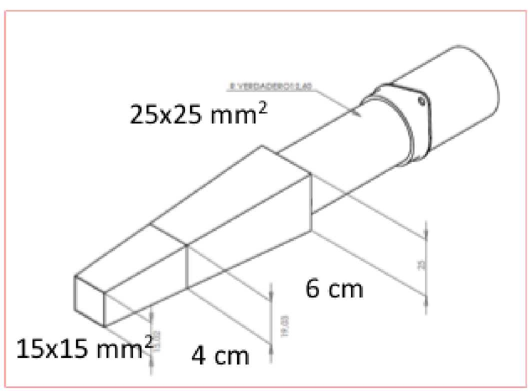
Lower E tail: Energy loss due to neutral production at the end (LaCl)

Higher E tail: Energy loss due to neutral production at the begining (LaBr)

Final peak: Knock-out of 1 proton in Br, Cl or La 7KeV<E







GEANT4 simulations

- TEFLON 1 mm between crystals and at the entrance window
- Hadronic processes included.
- Energy resolution included (experimental).

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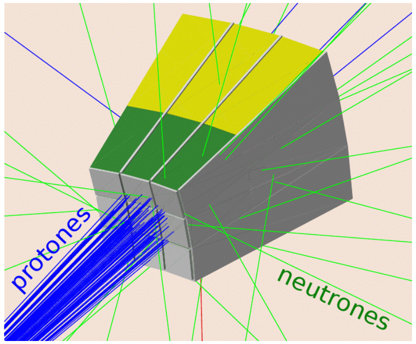
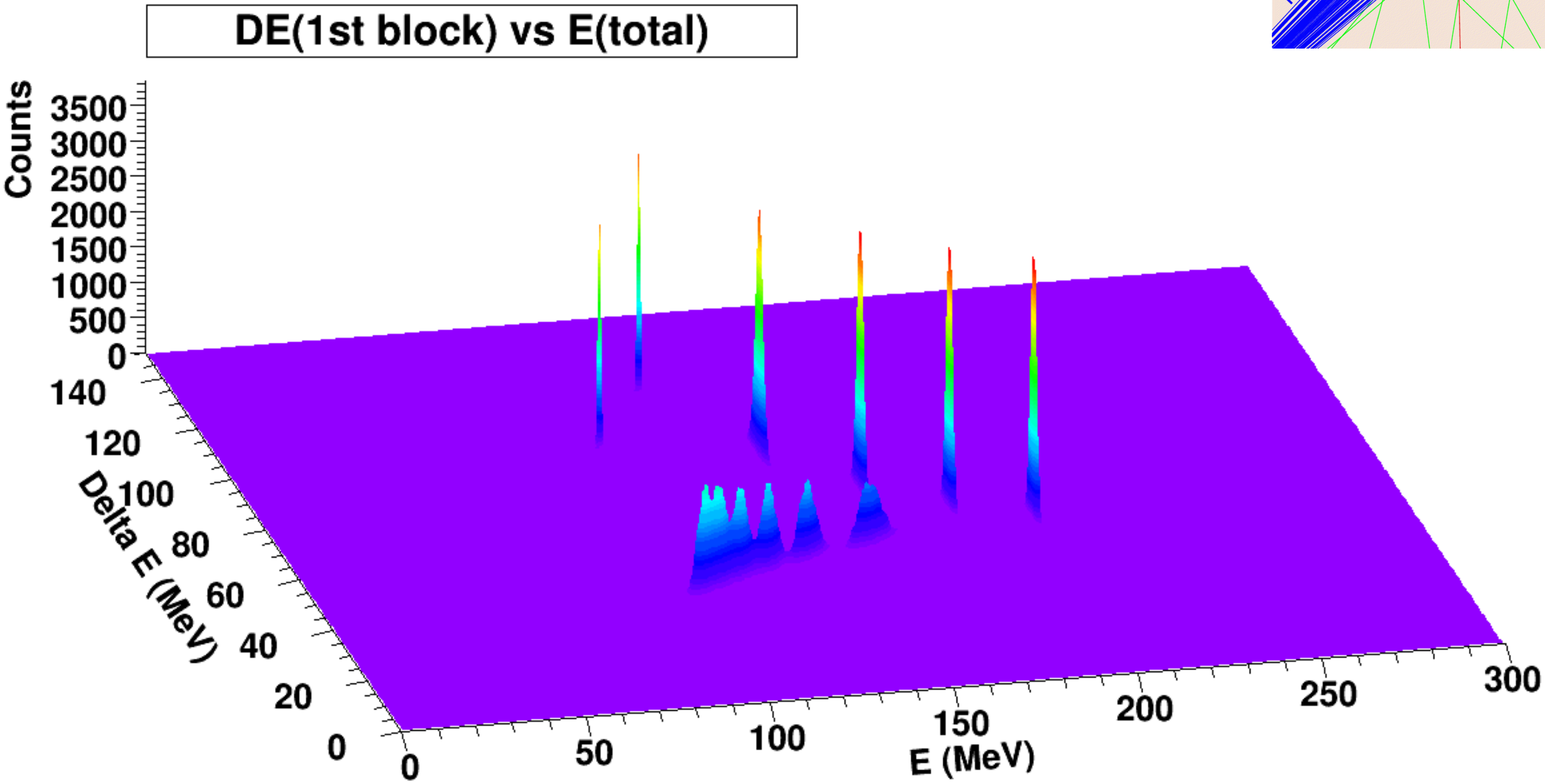
Protons in CEPA

- 2D graph ΔE-E_{tot}

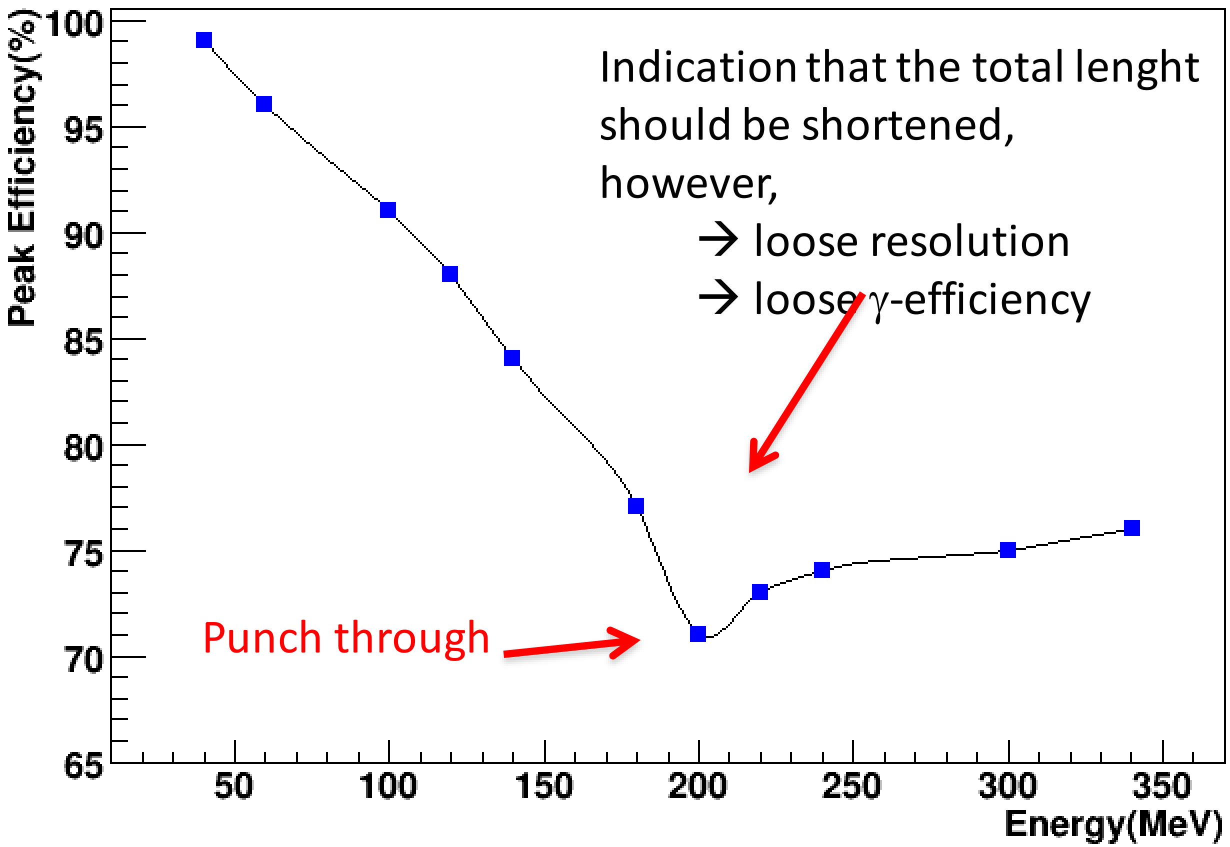




Protons in CEPA

- Proton peak efficiency

Note the scale



Detector considerations

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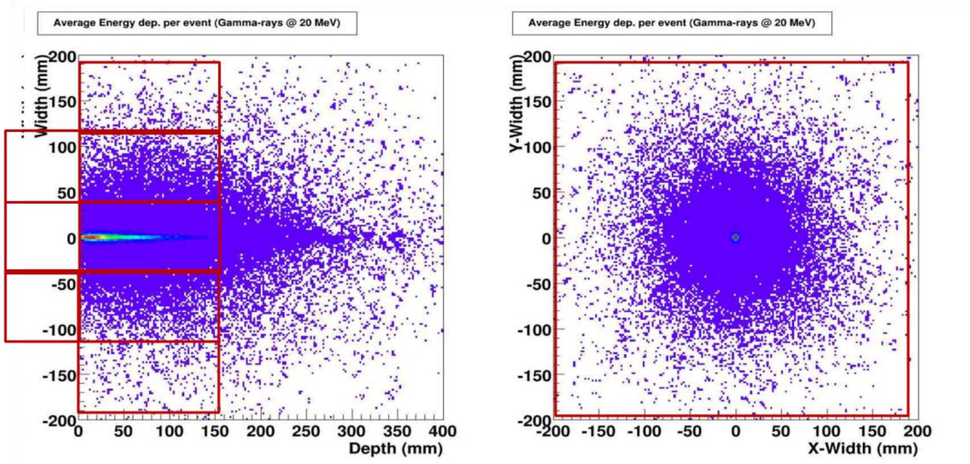
Calorimetry: Geometry to absorb Gamma-rays

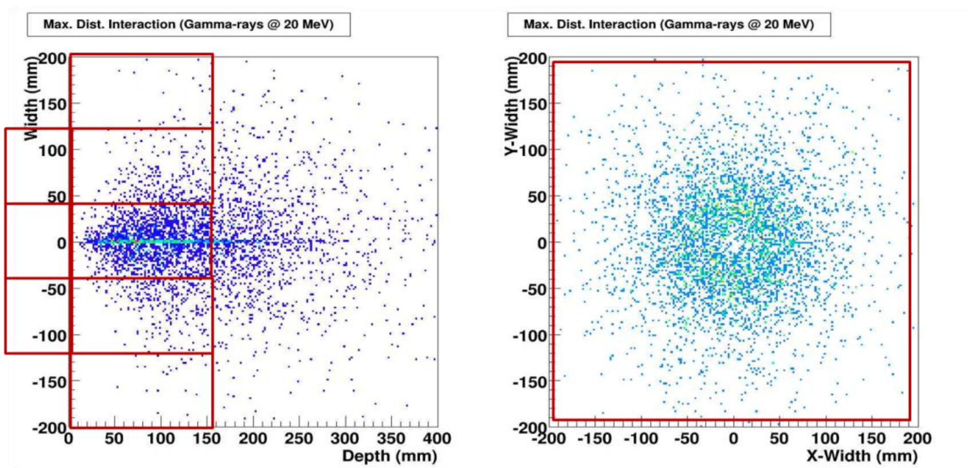


Gamma radiation average energy deposit per event inside an infinite volume of LaBr detector

Considering an infinite volume of $LaBr_3$ 87% of the gamma energy at 20 MeV is deposited within a rectangular prism of 15 cm length 10x10 mm^2 entrance area

→ 91 % efficiency with full add-back from "neigbouring" rectangles

Spectroscopy: Optimize "Photo-peak" efficiency



Maximum distance between interactions - absorbing one incident gamma inside a crystal 10x10x150mm^3

Photopeak efficiency			full add-back
@ 10 MeV	36 %	→	74 %
@ 20 MeV	16 %	→	66 %
@ 30 MeV	7 %	→	56 %

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Summary

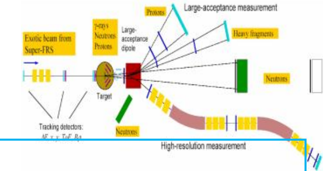
- **FAIR will become a world-class centre for major parts of the subatomic physics**
  - Modularised version maintains competitiveness in all scientific domains

- **NUSTAR community combines a vast number of complementary exp. Facilities & methods to study the nuclear structure**
  - Low Energy, High Energy and Ring Branch
    - Hispec, Despec, Mats, Ilima, R3B, Exl, Elise …

- **R^3B - Reactions with relativistic radioactive beams yield unique possibilities for studies of nuclear systems at the extremes, based on a generic fixed-target set-up**
  - Fully adapted to Super-FRS production method

- **R&D enlarging the experimental toolbox at R^3B requires cutting-edge instrumentation**
  - Has to be accompanied by efficient methods for data handling and analysis

CALIFA



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R^3B collaboration

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ATOMKI, Debrecen, Hungary
CCLRC Daresbury Laboratory, UK
CEA Saclay, France
Chalmers Uni of Tech, Göteborg, Sweden
IFIC - CSIC, Valencia, Spain
CUPP project, Pyhaesalmi, Finland
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GANIL, Caen, France
GSI, Darmstadt, Germany
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IPN Lyon, France
IPPE Obninsk, Russia
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Johannes Gutenberg Univ, Mainz, Germany
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Justus-Liebig-Univ, Giessen, Germany
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Tata Inst of Research, Mumbai, India
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Univ Santiago de Compostela, Spain
Universität zu Köln, Germany
Univerity of Bergen, Norway
University of Birmingham, UK
University of Complutense Madrid
University of Keele, UK
University of Liverpool, UK
University of Manchester, UK
University of Paisly, UK
University of Surrey, Guildford, UK
University of York, UK
Yale Univerity, USA

R^3B collaboration:
50 institutes
180 scientists

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Thank you for the attention!