CALIFA: a new generation calorimeter for reaction studies at relativistic energies

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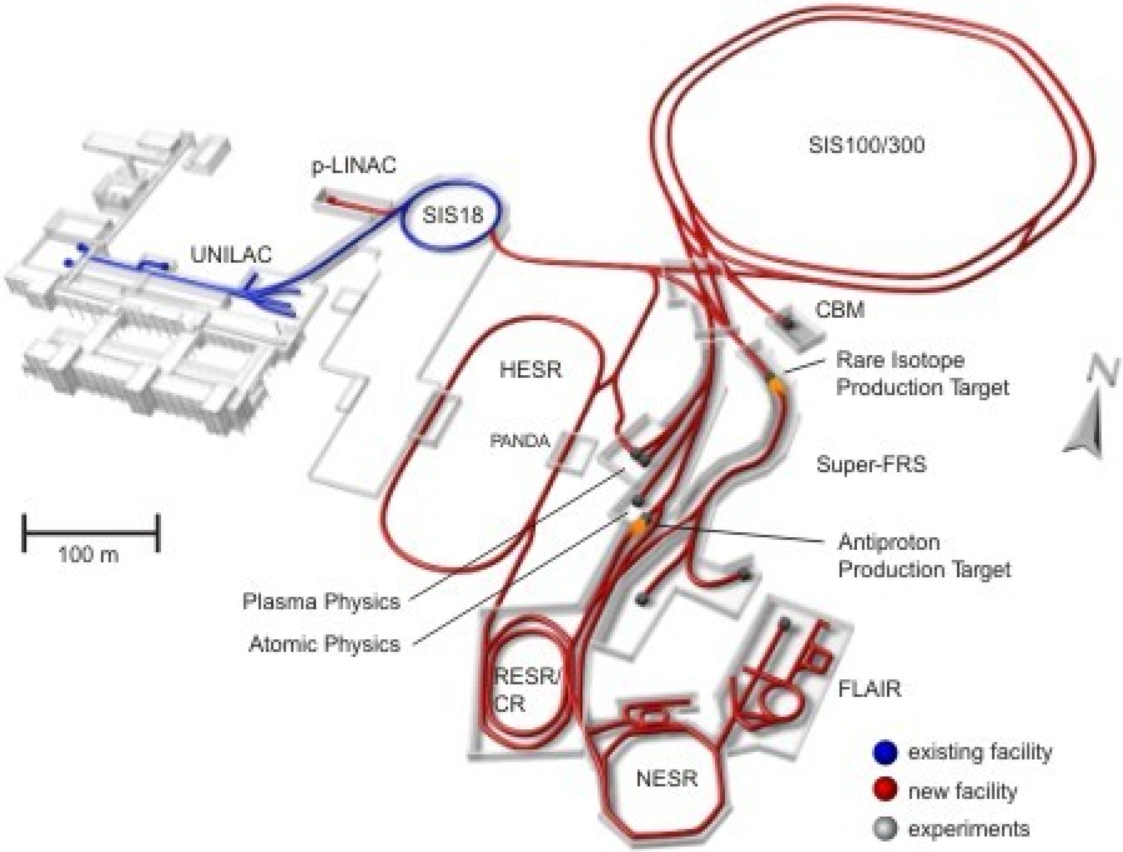
FAIR: Facility for Antiproton and Ion Research

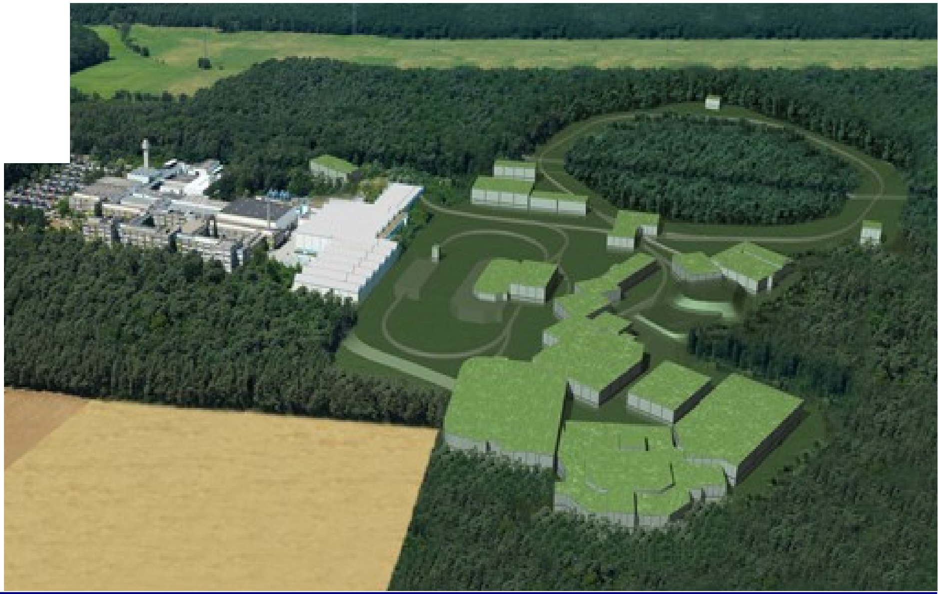


Scientific program

- Nuclear structure and Astrophysics with stable and **exotic** nuclei
- Hadronic Physics with antiprotons
- Relativistic heavy ion collisions
- Atomic and Plasma Physics

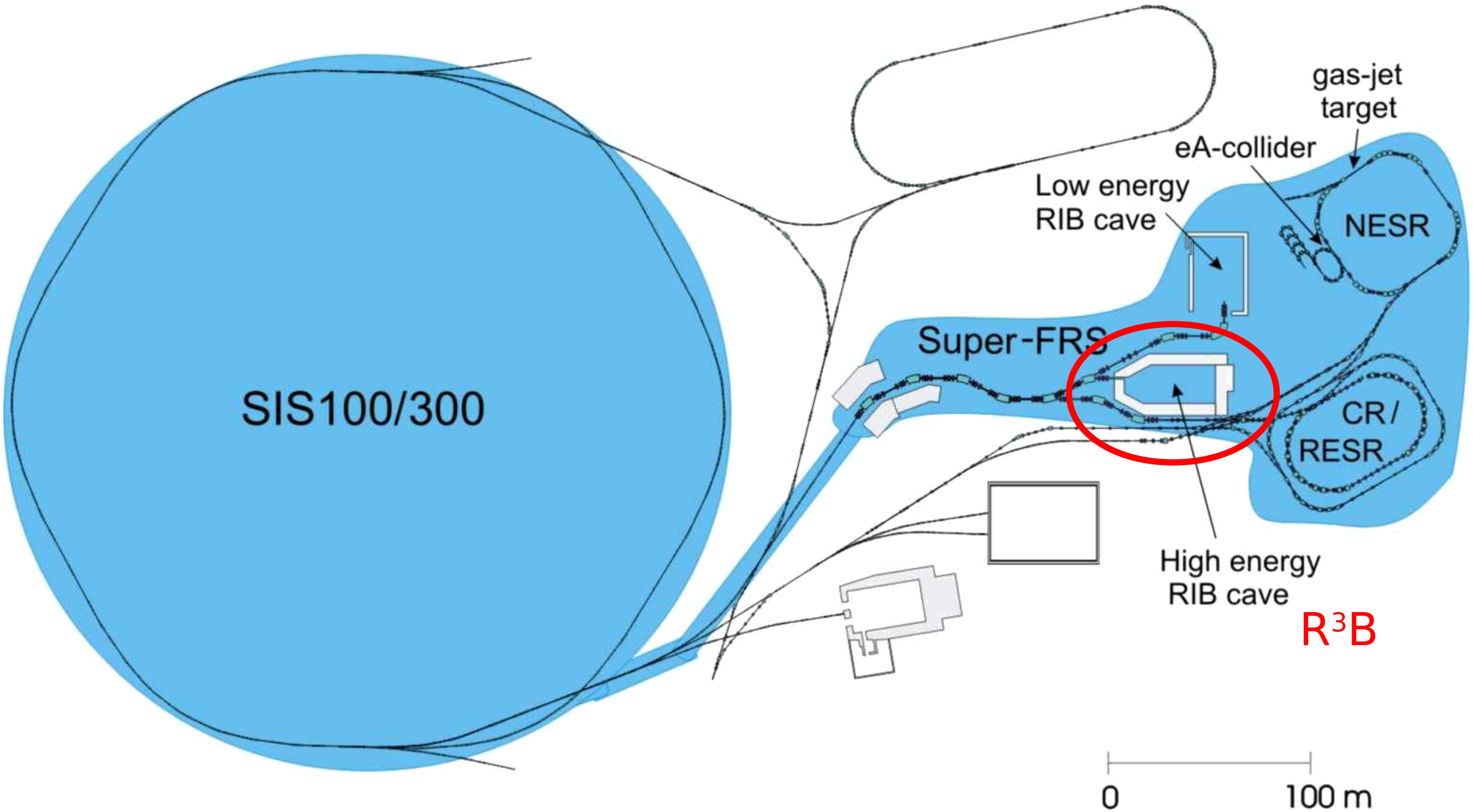
FAIR Accelerator Facility next to GSI @ Darmstadt, Germany

- New superconducting synchroton double ring (SIS 100/300, 1100 m circunference, magnetic rigidities 100/300 Tm)
- Ion beams with highest beam intensity and higher energies
- Primary intensities: (10^{12} iones/s)@ 2-30 GeV/u.
- Super-FRS separates in-flight rare isotopes with extraordinary phase-space acceptance, from projectile fragmentation or fission



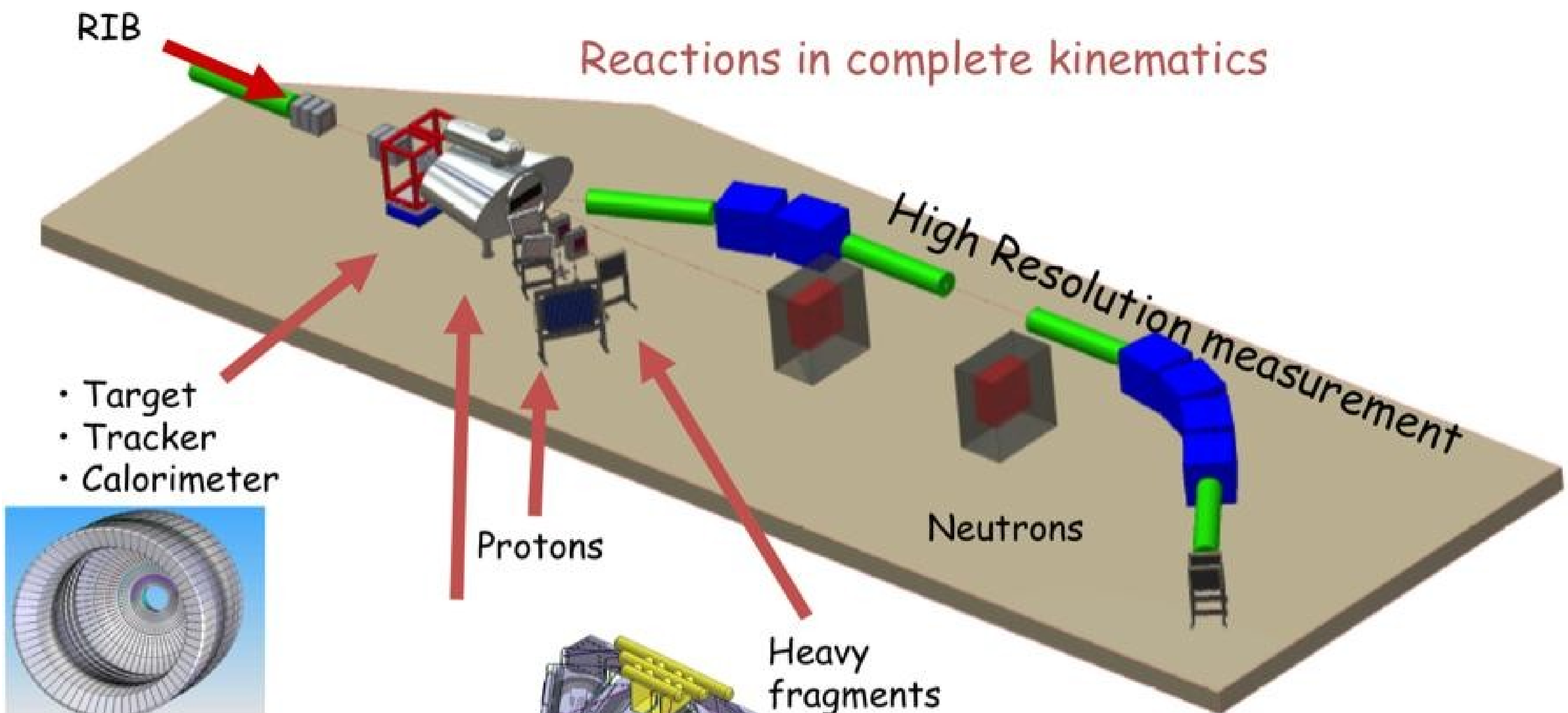
R^{3}B at FAIR planning

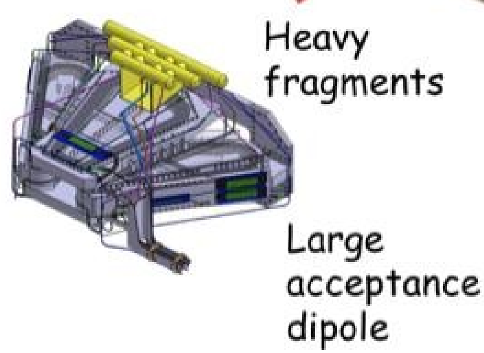
http://www.gsi.de/fair/index_e.html



Reactions with Relativistic Radioactive Beams

R3B: Physics program





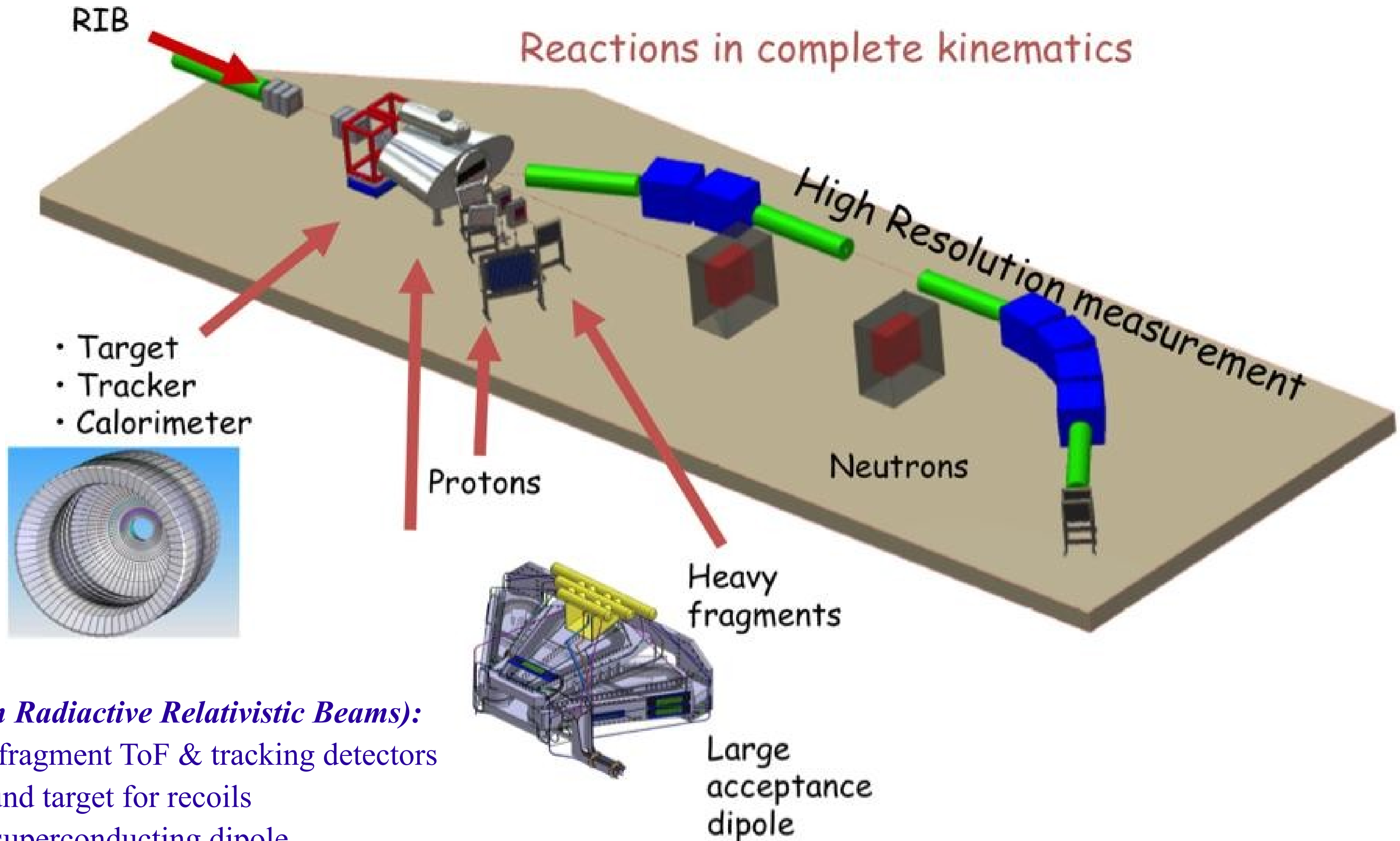
R3B Physics programs comprehends:

- Knockout – shell structure, resonances, ...
- QFS – Structure functions, correlations, ...
- Total absorption reactions – halo, nuclear radius, ...
- Elastic scattering – Nuclear density, ...
- EM excitations – Transition strengths, ...
- Fission – Structural and dynamic properties, ...
- Spalation – Reaction mechanims, astrophysic applications, transmutation, ...
- Fragmentation – EOS!

***The most sensitive observables require simultaneous measurement of neutron and protons, i.e., neutron-proton differential quantities*.**

B. Li – Arkansas State Univ.

R³B: Reactions with Radiactive Relativistic Beams



R³B (Reactions with Radiactive Relativistic Beams):

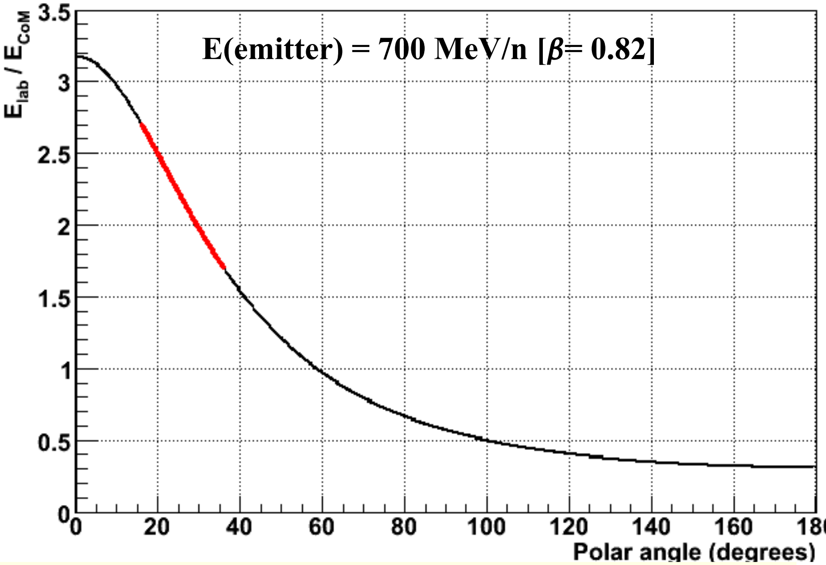
- Beam, proton and fragment ToF & tracking detectors
- Silicon arrays around target for recoils
- Large acceptance superconducting dipole
- High resolution neutron detectors
- Calorimeter / gamma spectrometer

http://www.gsi.de/forschung/kp/kp2/collaborations/R3B

The R3B Calorimeter: CALIFA design principles

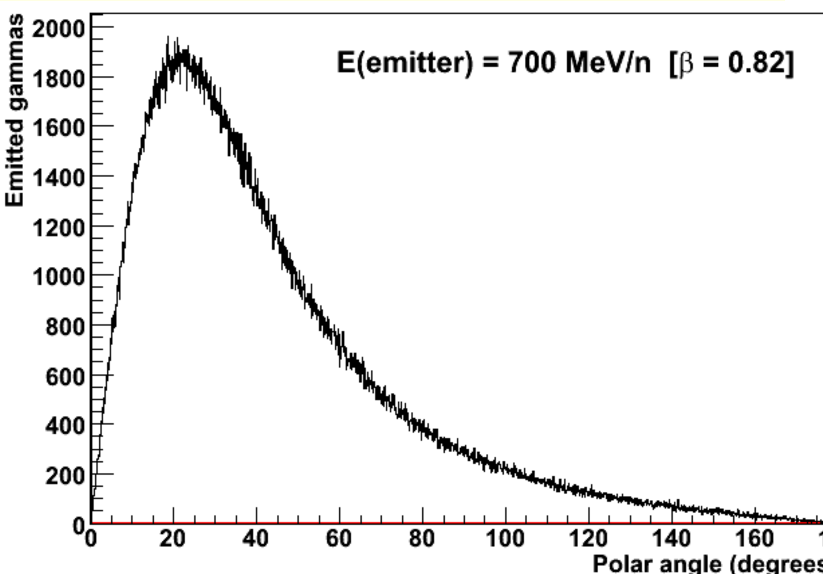
The Calorimeter requirements (R3B LoI, 2005) comprise:

- A total absorption efficiency of about 80% up to E = 15MeV Lab
- A gamma energy resolution of $\Delta E_{CoM}/E_{CoM} \sim 3\%$ (FWHM)
- A proton energy resolution better than 1% (FWHM) up to 300 MeV
- A gamma multiplicity: $\sigma(N)/\langle N\rangle < 10\%$
- A gamma sum energy: $\sigma(E_{sum})/\langle E_{sum}\rangle < 10\%$
- Reasonable cost!



But note the particular kinematics due to the relativistic incoming beams:

- The Lorentz boost shifts the gammas energy up to x3 in forward direction (at 700 MeV /n, and even more at larger energies)
- The gamma CoM energy reconstrucion depends strongly on geometry, in particular on the polar angle resolution $\sigma(\theta)$
- A large granularity [$\propto \sigma(\theta)$, variable with θ] is requested!
- An enhanced forward emission, peaked around 30 degrees (β~0.82)



...then, the R^3B Calorimeter should feature:

- A sufficient granularity in θ for a reasonable gamma CoM energy reconstruction; a ϕ granularity for a suitable crystal shape
- An adapted crystal lengths at different polar angles
- A compact size, no gaps to increase the efficiency, no escape lines from target without crossing active detector
- A small number of different crystal types, with optimal design

CALIFA: task distribution

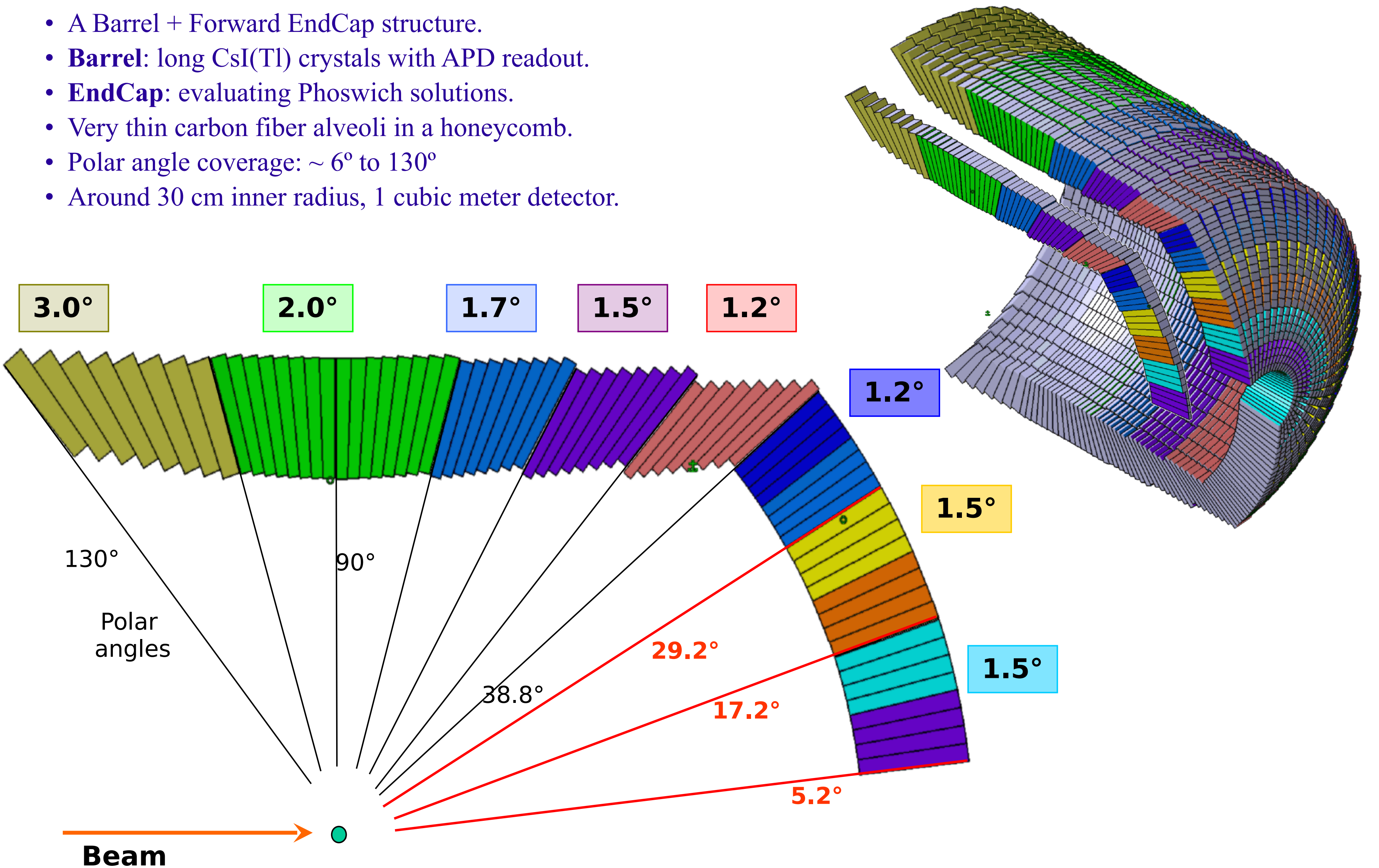
R3B/CALIFA coordinator D. Cortina USC

USC, IEM, UVi (SPAIN), LUND,Chalmers (SWEDEN),TUM,TUD, GSI (GERMANY), POLAND, RUSSIA, ULIS (PORTUGAL), INDIA

- Mechanical design Uvi,USC,IPN
- Crystal and photosensors BARREL USC,LUND, IPN
- Crystal and photosensors FORWARD IEM, Chalmers, USC
- Simulations USC, LUND, IEM, ULisboa
- Slow control TUD
- Electronics TUD,IEM, USC, INDIA
- DAQ GSI (Common task within R^3B)

CALIFA design basics (USC, Univ. Vigo)

- A Barrel + Forward EndCap structure.
- **Barrel**: long CsI(Tl) crystals with APD readout.
- **EndCap**: evaluating Phoswich solutions.
- Very thin carbon fiber alveoli in a honeycomb.
- Polar angle coverage: ~ 6º to 130º
- Around 30 cm inner radius, 1 cubic meter detector.



H. Alvarez *et al.* NIM B 266 (2008) 4616-4620

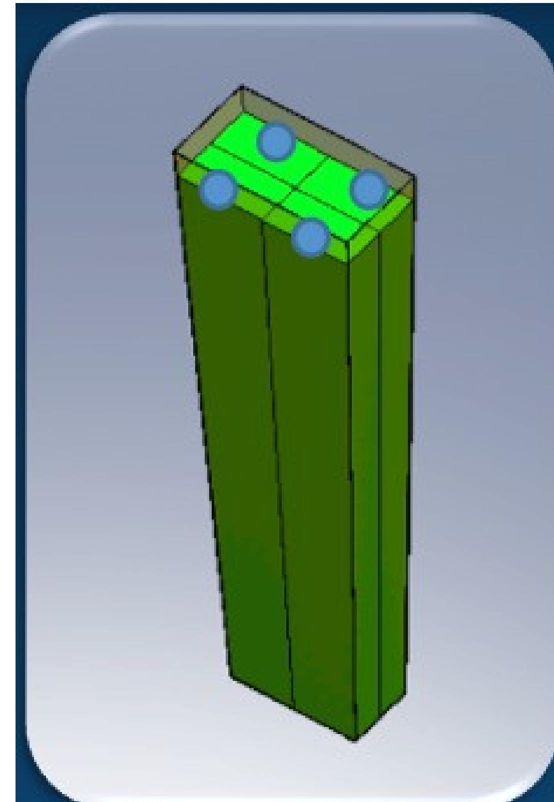
CALIFA alveoli mechanical design

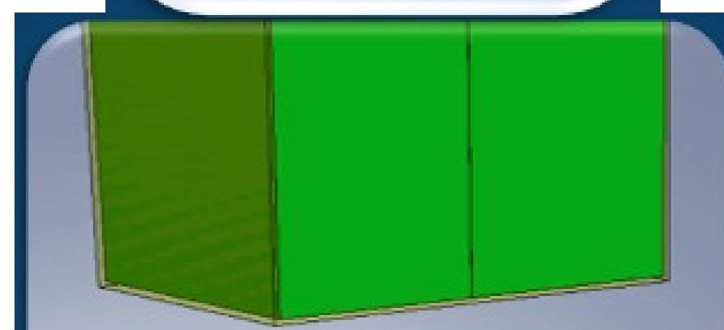
- Carbon fiber alveoli glued with epoxy resin adding strengtheners.
- Double 160 micrometer wall thickness (trying to reduce!).
- Very good light weight – strength relation.
- Divided in parts for maintenance and inner detectors access.

6 Types of Alveoli.
6 Types of Crystals(x2 L-R versions)
Dimensions:

alveoulus type	Base Length (mm)		Angular Aperture (degree)	
(*) (**) (***)	polar	azimuthal	polar	azimuthal
I	25,0	47,0	91,20	92,50
II	25,0	47,0	91,50	92,85
III	24,5	47,0	91,95	93,70
IV	25,0	47,15	92,20	94,00
V	35,0	47,0	92,50	93,50
VI	35,0	47,0	92,50	93,10

(*) NB all types are defined with two lenght and two angles (polar and azimuthal)
(**) NB lengths are external; wall thickness is 300 um in the model
(***) NB types ordered from lower to higher polar angle

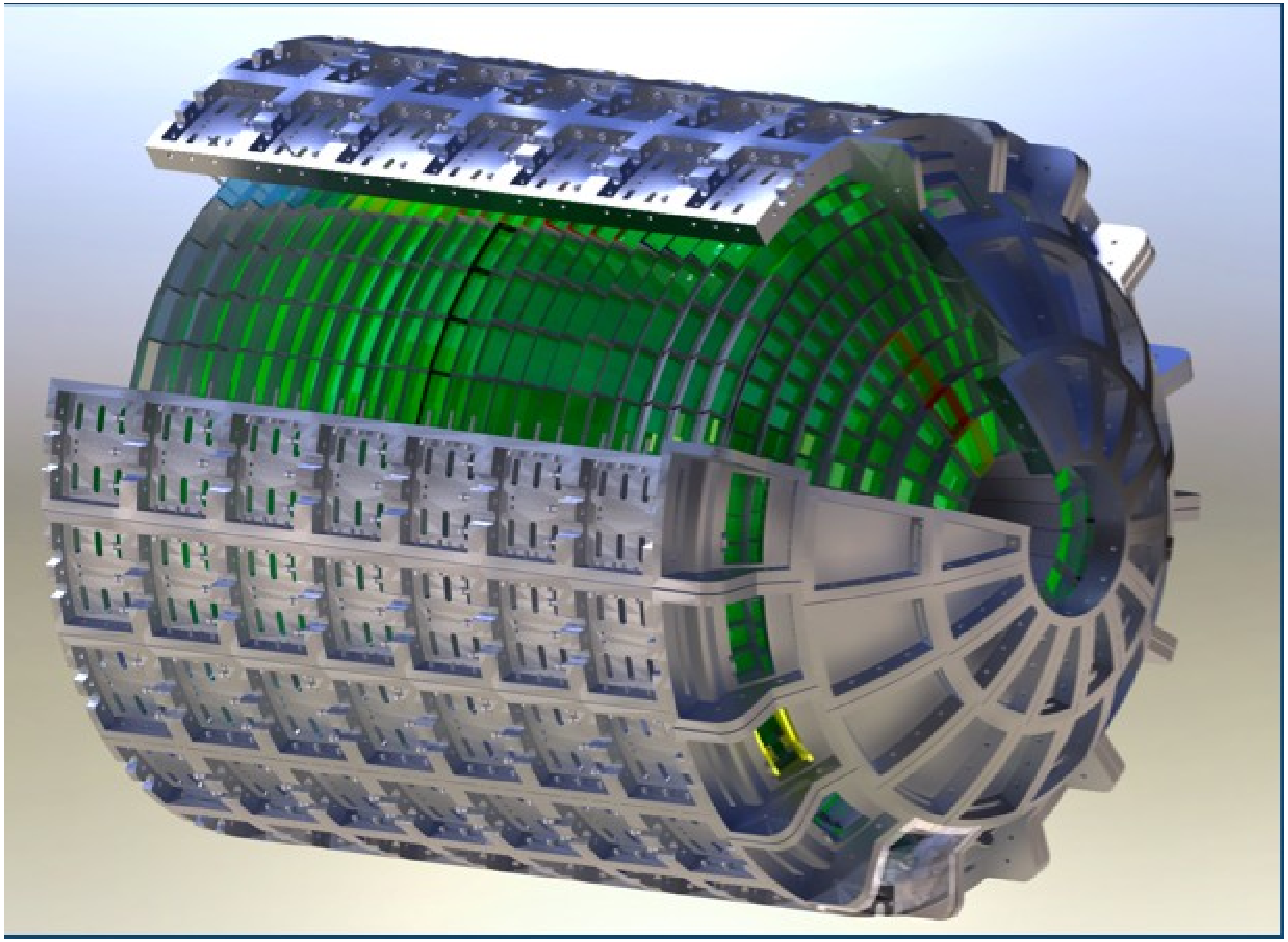


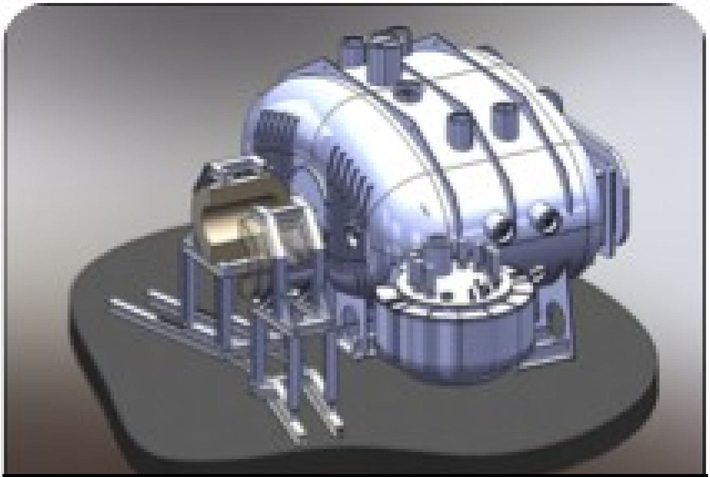


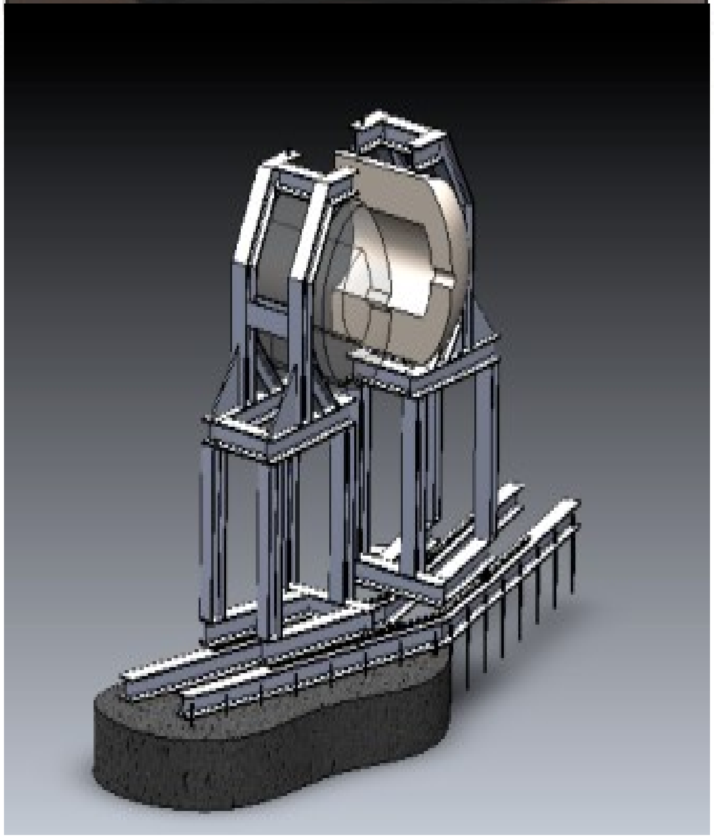
Total adjustment to alveoli base

CALIFA mechanical design

- Modular aluminum structure covering preamplification electronics
- Sealing the calorimeter (hygroscopic crystals)
- Barrel dimensions: ~980 x 1040 mm^2
- Lineal guides for inner access, adjustable total heigth
- Self supporting calorimeter halves. **Studying other aperture modes**.



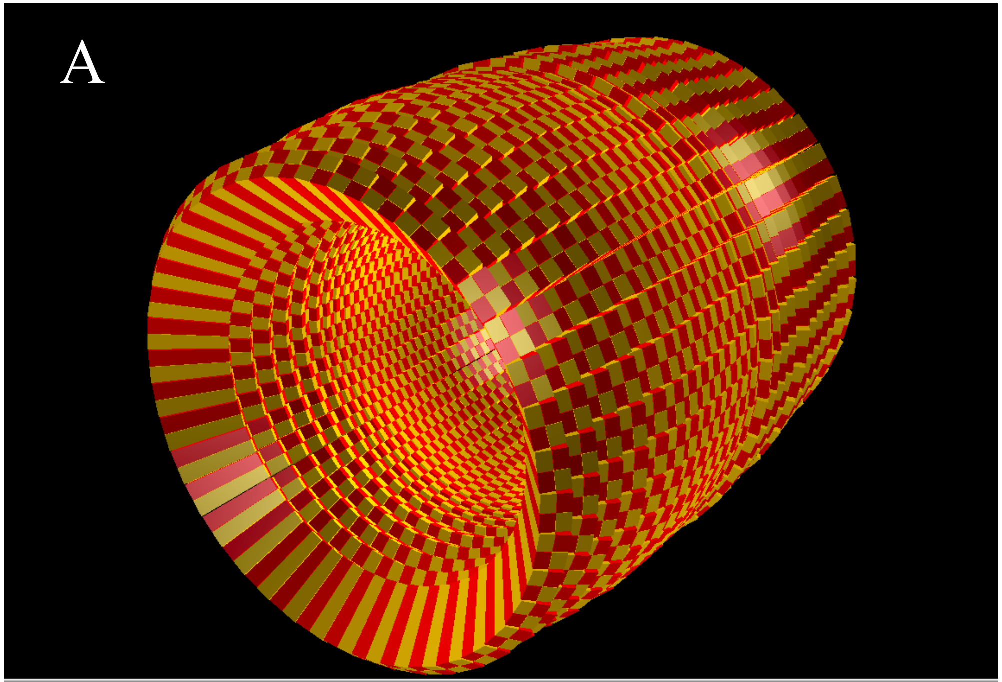


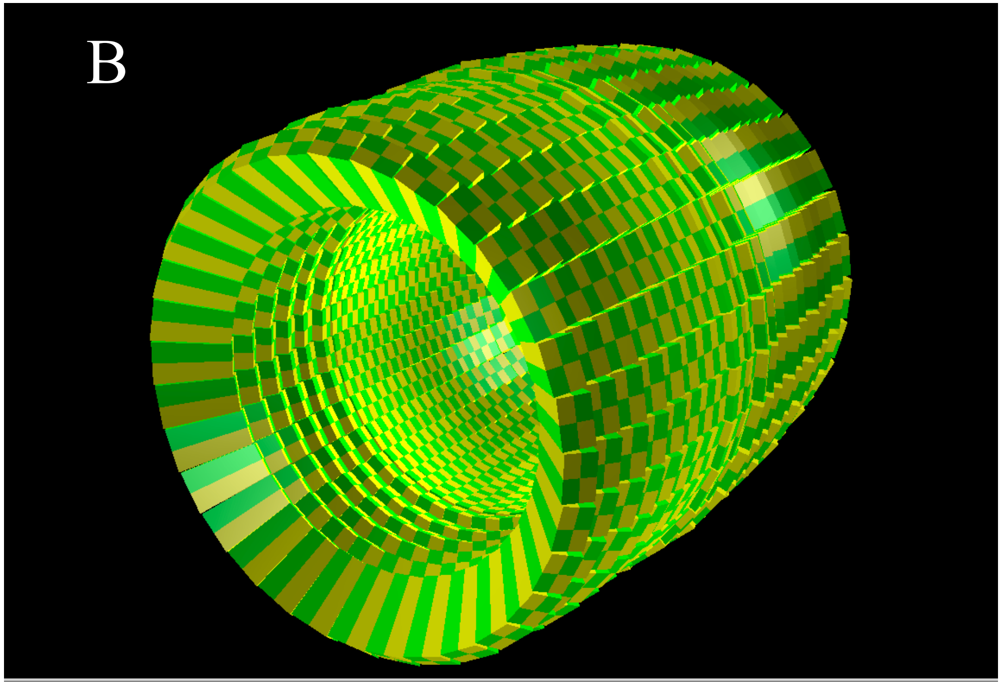


CALIFA configurations under study

Crystals	3840
Crystals by Ring	80
Crystals by polar direction	48
Crystals by alveolus	4
Alveoli	960
Alveoli by Ring	40
Alveoli by polar direction	24

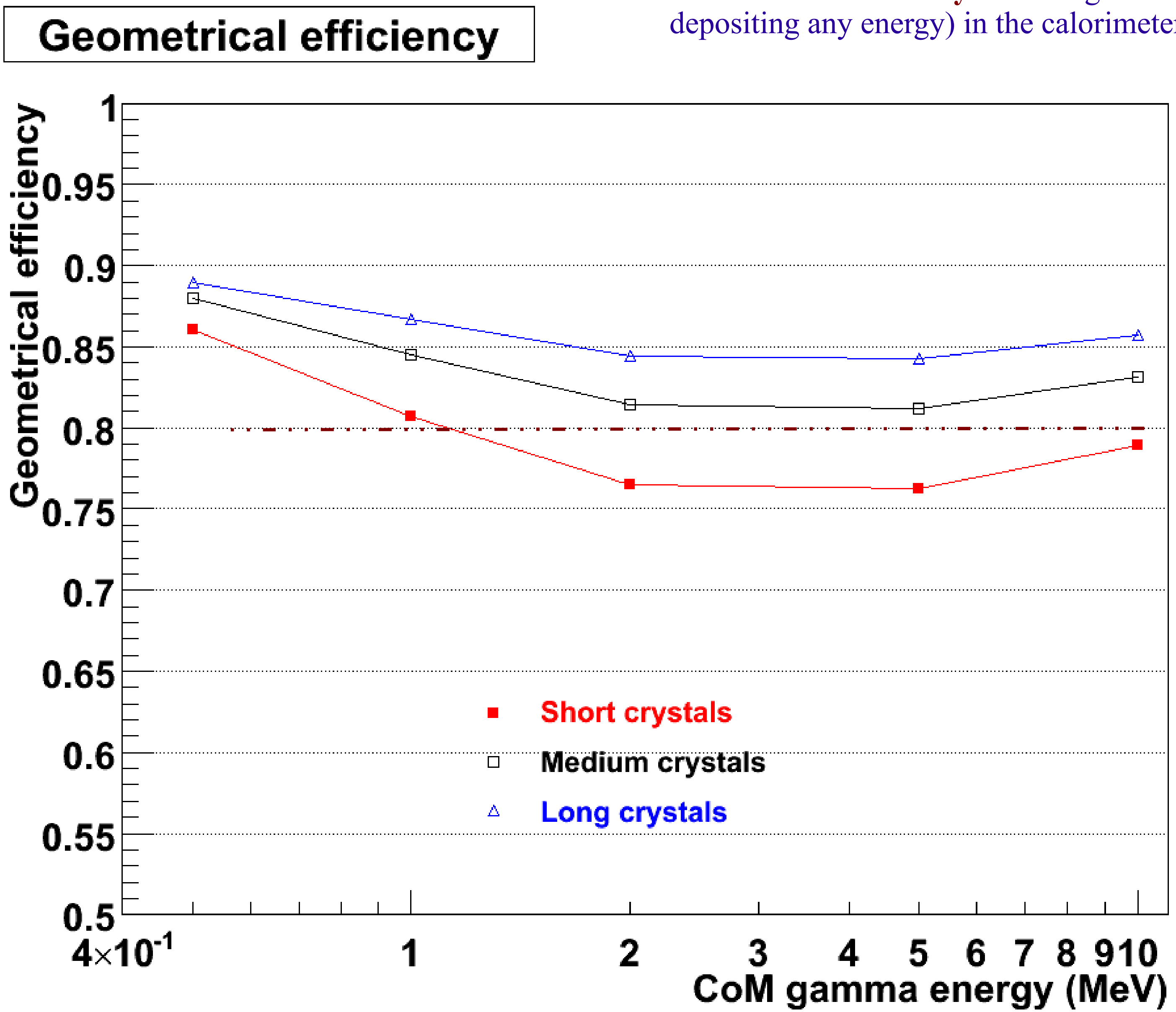
Crystals	2560
Crystals by Ring	64
Crystals by polar direction	40
Crystals by alveolus	4
Alveoli	640
Alveoli by Ring	32
Alveoli by polar direction	20





(old) CALIFA simulation results – Geometrical efficiency

Geometrical efficiency: ratio of gammas detected (that is, depositing any energy) in the calorimeter crystals



BARREL covers ~ 35% of events

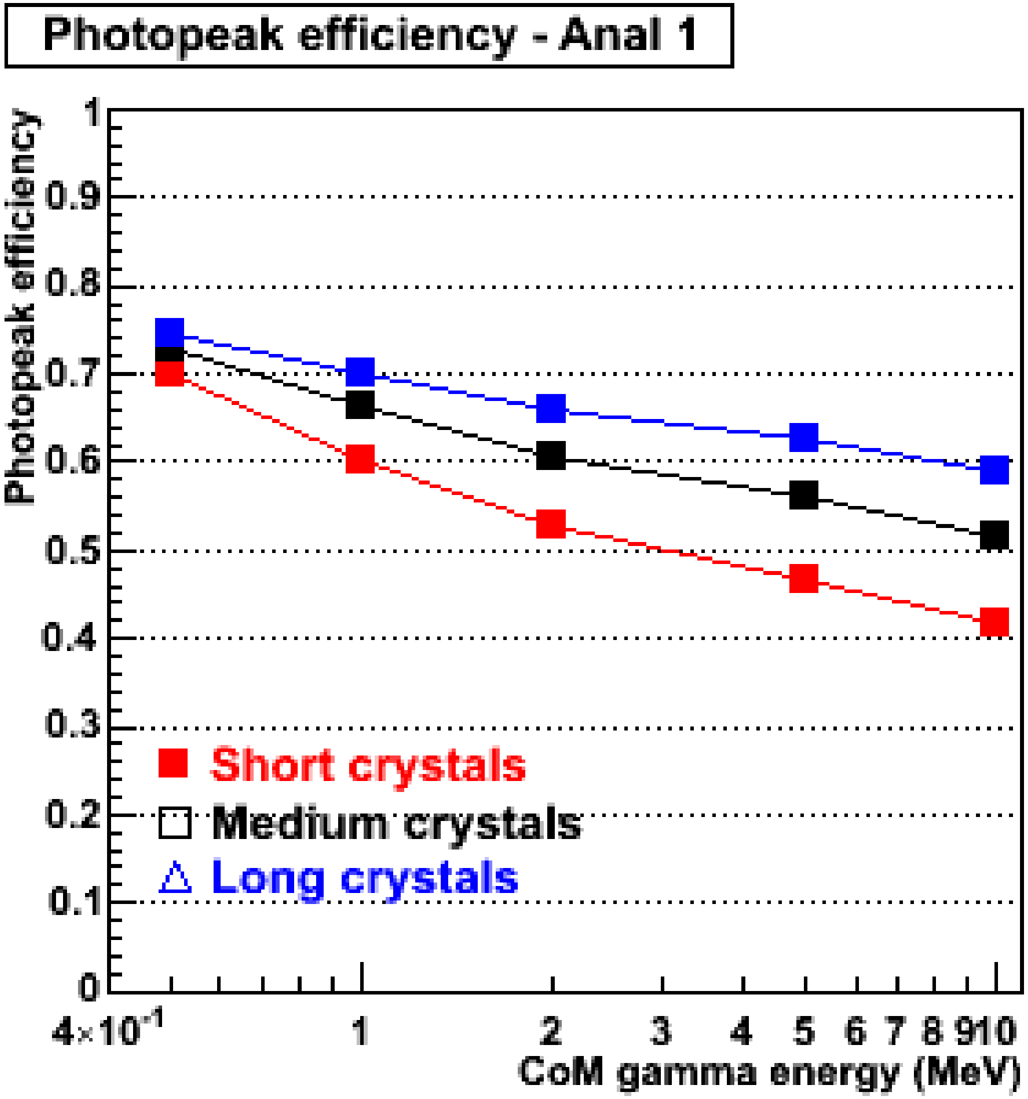
ENDCAP covers ~ 45% of events

(old) CALIFA simulation results – Photopeak efficiency

Photopeak efficiency: ratio of gammas detected under the photopeak

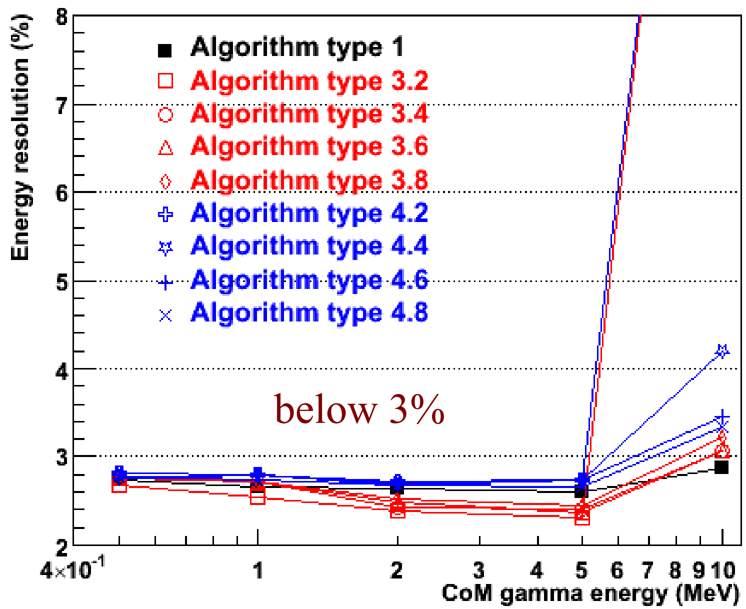
PE depends on energy, crystal length and slightly on the algorithm:

- Length : 2-8% increase changing to a larger size, lower PE for shorters
- Algorithm: better as more crystals involved, mainly at high energies
- Energy: drops ~20% going from 0.5MeV to 10MeV

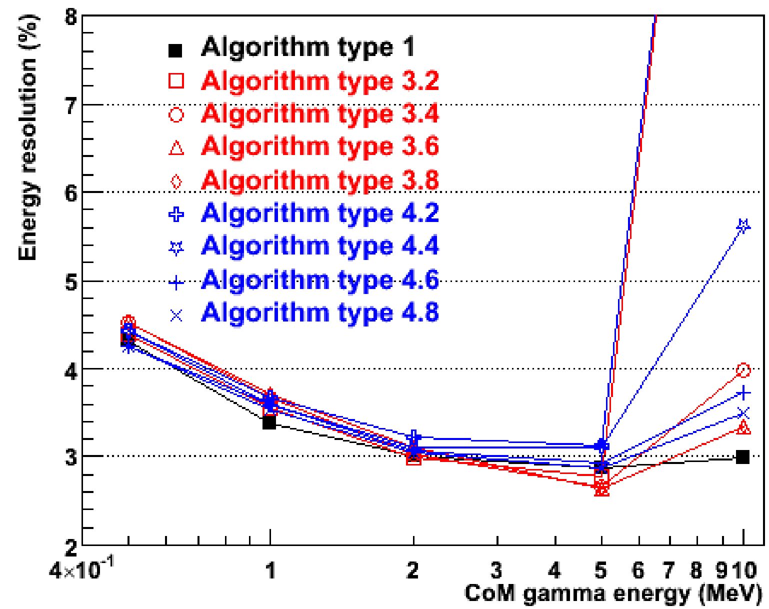


CALIFA simulation results – Energy resolution (FWHM)

Energy resolution for perfect resolution

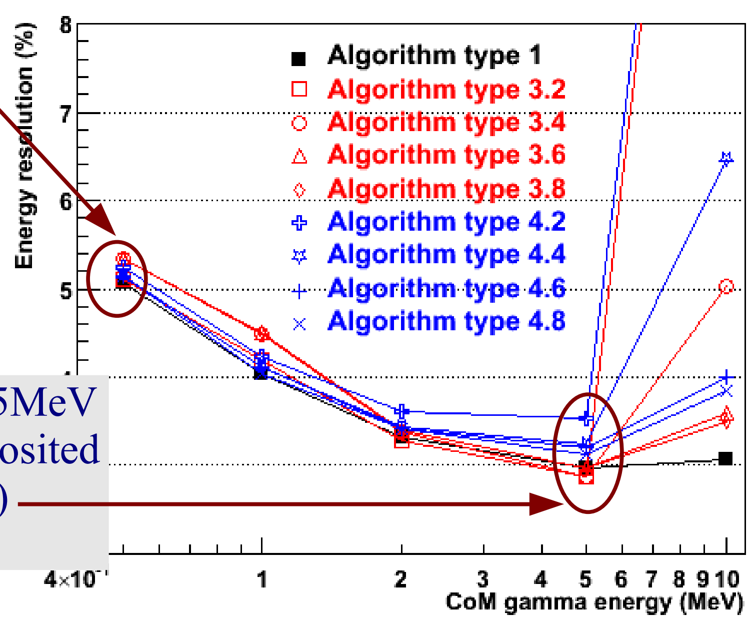


Energy resolution when crystal res. = 3%



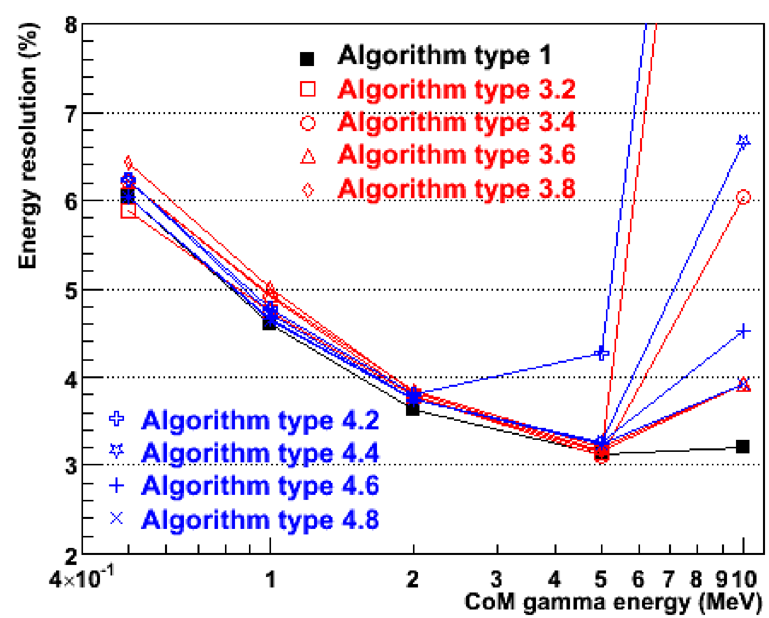
Energy resolution when crystal res. = 4%

Energy deposited in 1 or 2 crystals



4%@1MeV ~ 2%@5MeV but the energy is deposited in several crystals (4)

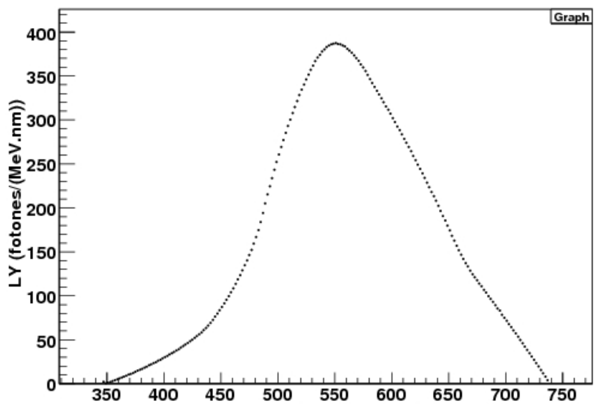
Energy resolution when crystal res. = 5%



Test on CsI(Tl) crystals + APDs: experimental setup

Experimental setup, highlights:

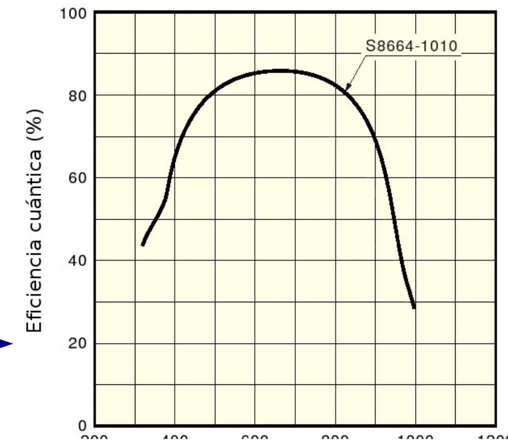
- ✔ CsI(Tl) is a reasonable and relatively cheap option
- ✔ Hamamatsu APDs QE matches CsI(Tl) emission wavelength



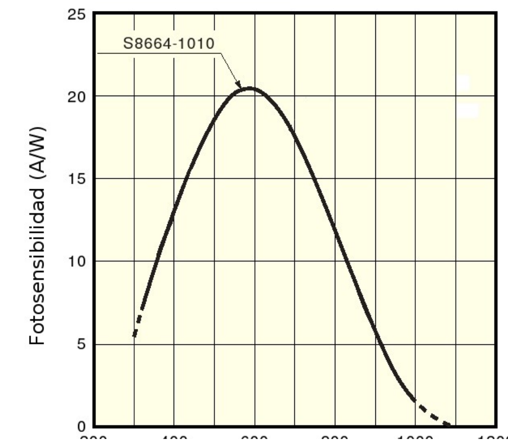
Wavelength (nm)

CsI(Tl) emission wavelength

LAAPD Quantum efficiency and Photosensibility

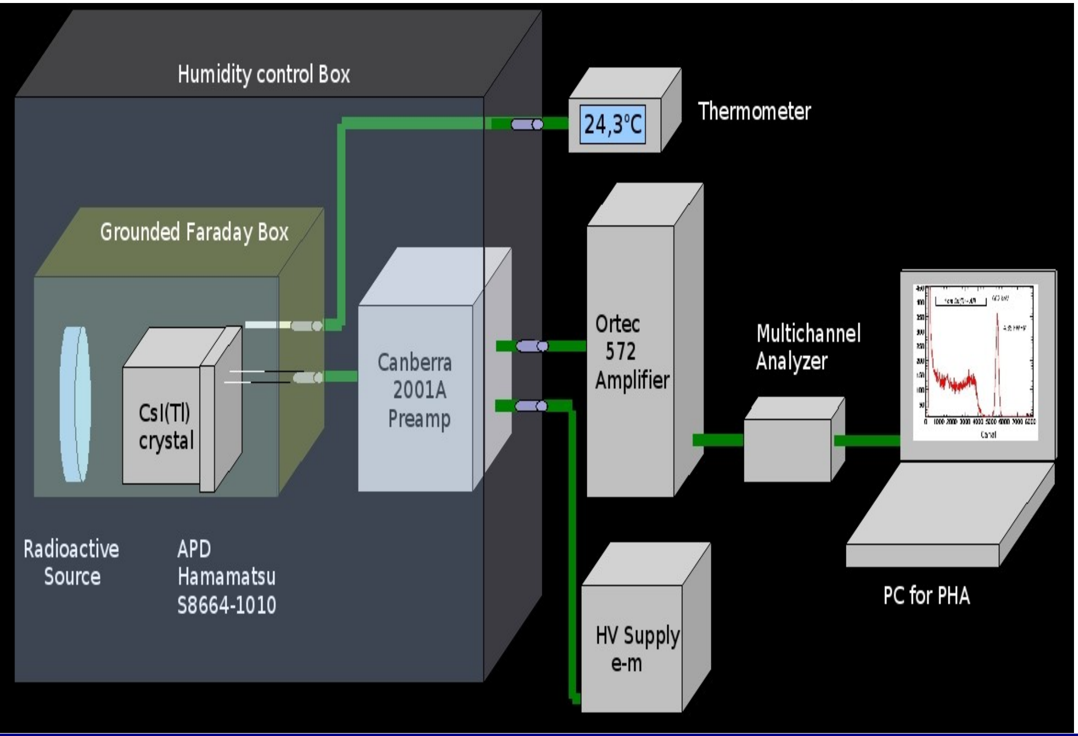


Wavelength (nm)



Wavelength (nm)

LAAPD HAMAMATSU S8664-1010



How do energy resolution behave with crystal length?

Experimental setup for the presented (next) results:

- ✔ CsI(Tl) crystals from St. Gobain, Scionix, Amcrys, Lanzou, ...
- ✔ Hamamatsu LAAPD S8664-1010, -55, -714, ...
- ✔ Camberra 2001A preamp + Ortec 572 Amplifier, other elec. chains tested (Ortec142 + Canberra 2022, Cremat CR110,...)
- ✔ A black grounded Faraday box, with humidity control and temperature monitorization (0.1C resolution)
- ✔ Other tests with API UV and different with Photonis PMs, different electronics and crystals from other providers...

Test on CsI(Tl) crystals; energy resolution

Best results for CsI(Tl) coupled to S8664-1010 Ham. APD

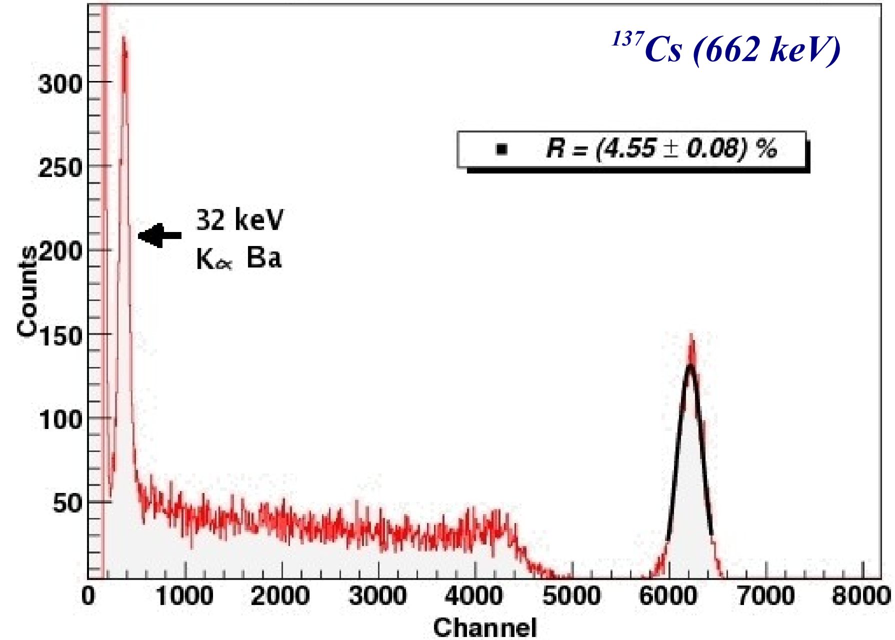
Energy resolution	Crystal size		
Shapping time	1 cm	5 cm	10 cm
4 μs	4.68 ± 0.12	5.11 ± 0.12	4.74 ± 0.12
8 μs	4.42 ± 0.12	4.87 ± 0.09	4.72 ± 0.08

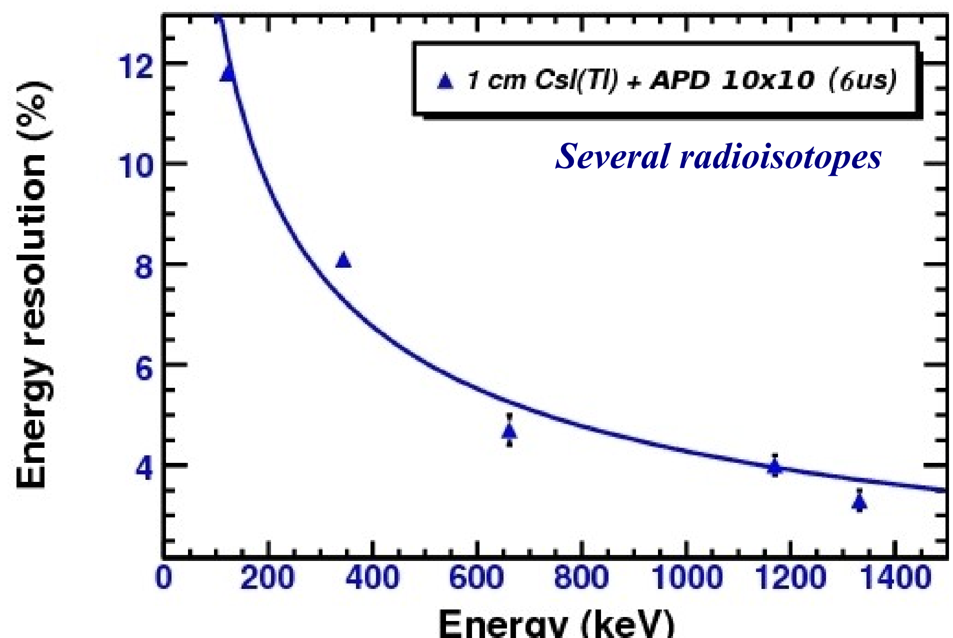
Mean results for CsI(Tl) coupled to S8664-1010 Ham. APD

Energy resolution	Crystal size		
Shapping time	1 cm	5 cm	10 cm
4 μs	4.98 ± 0.12	5.22 ± 0.09	5.17 ± 0.09
8 μs	4.68 ± 0.12	5.02 ± 0.12	4.90 ± 0.09

Best results for CsI(Tl) coupled to SD630-70-73-500 AP APD

Energy resolution	Crystal size		
Shapping time	1 cm	5 cm	10 cm
4 μs	4.57 ± 0.08	5.22 ± 0.09	-
8 μs	4.41 ± 0.10	4.99 ± 0.11	-





Energy resolution tests conclusions:

- ✔ Very good energy resolution, results comparable (or better) than those available in the literature
- ✔ Low energy threshold, below 20 keV for most cases
- ✔ Quite independent of the electronic chain
- ✔ Energy resolution (%, FWHM) behaves nicely as √E

M. Gascón et al. SCINT07, H. Alvarez et al. NSS 07.
IEEE Trans. on Nucl. Sci., vol. 55, issue 3, pp. 1259-1262 (2008)

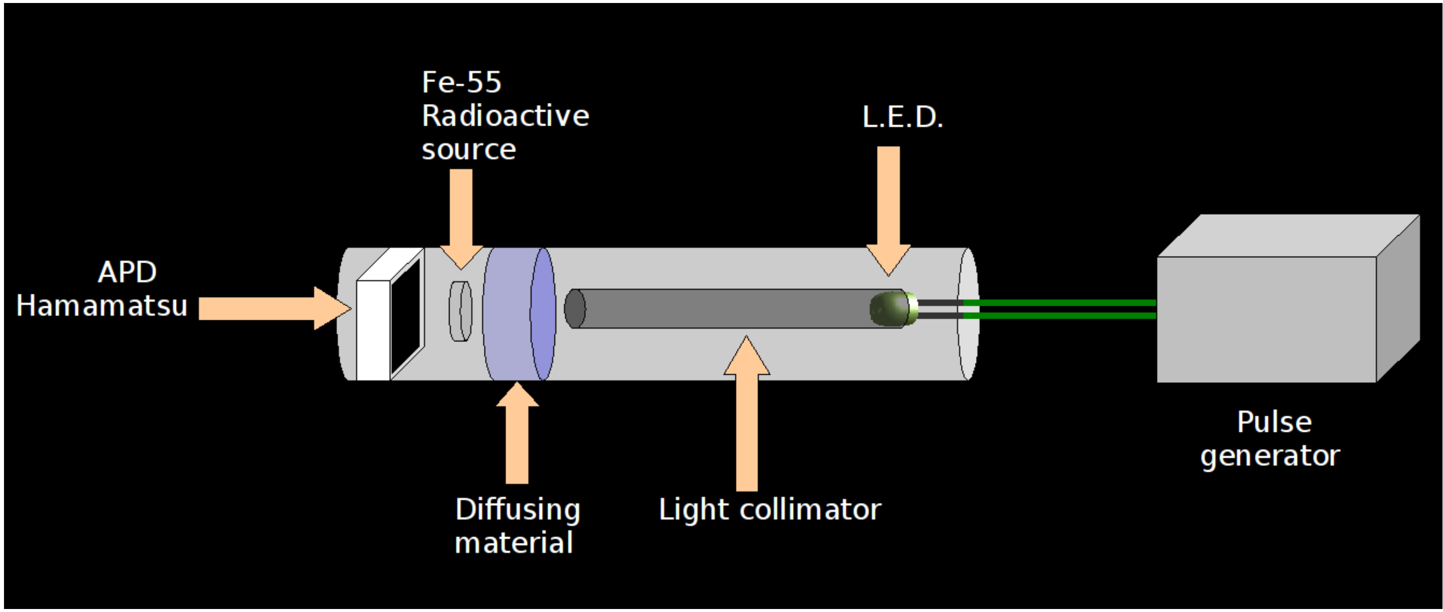
Characterization of APDs: test setup

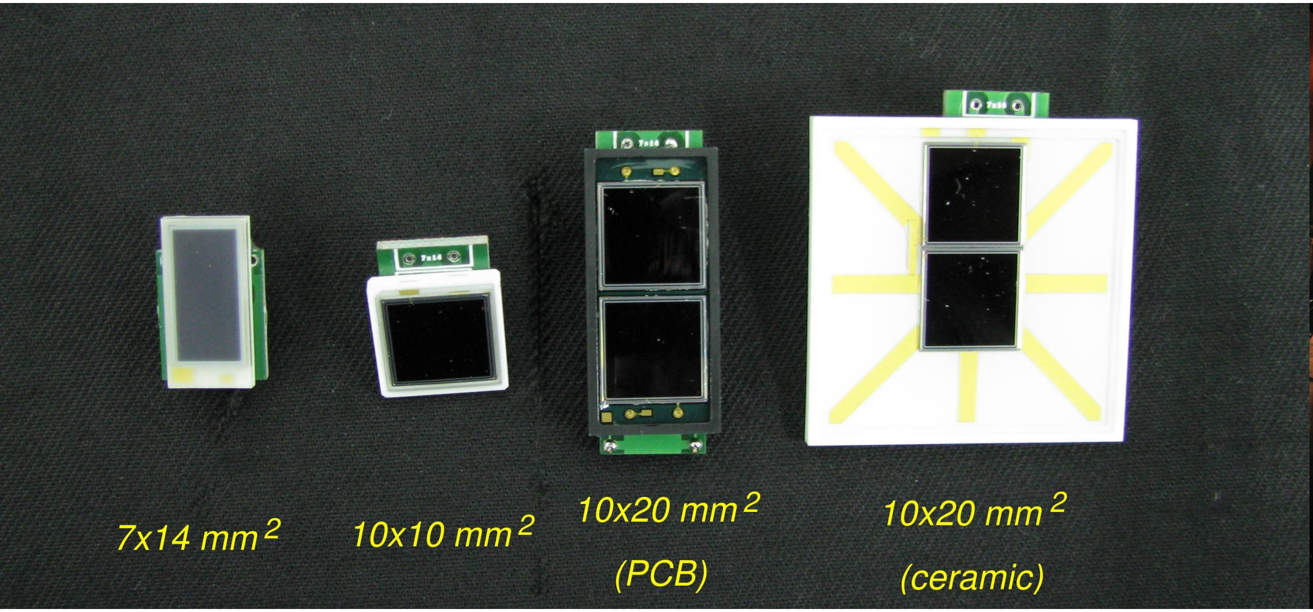
Goals of this test

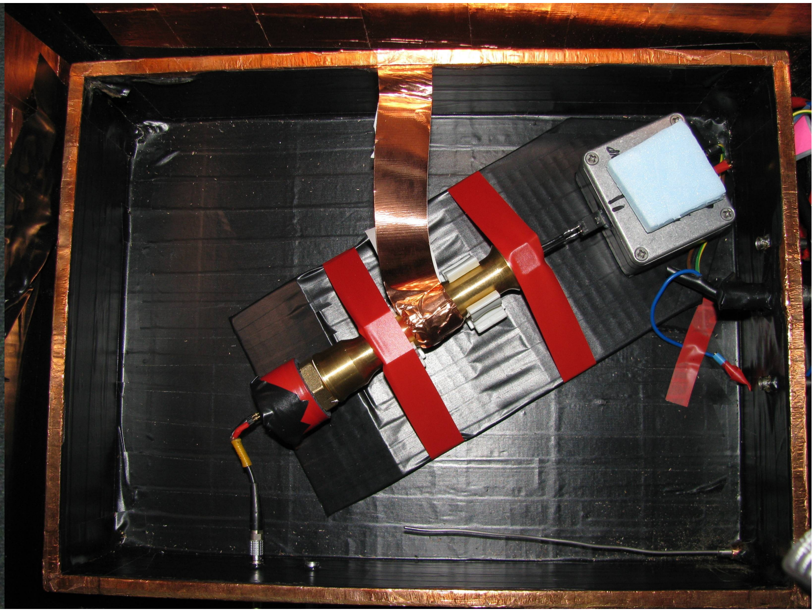
- Characterize APDs
- Disentangle the APD contribution to the total energy resolution

Experimental setup

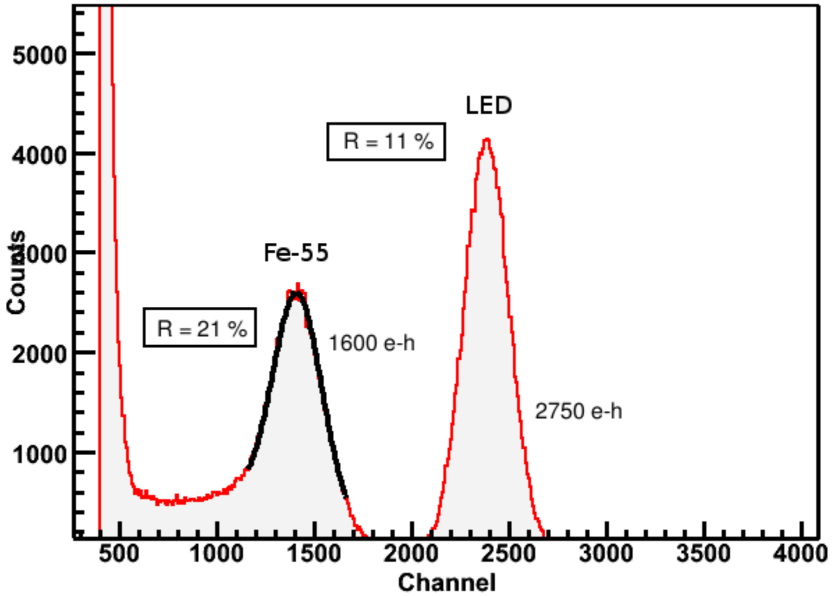
- A green L.E.D. Centered on the maximum vawelength of the CsI(Tl) emission
- A ^{55}Fe radioactive source to quantify the number of electron-hole pairs





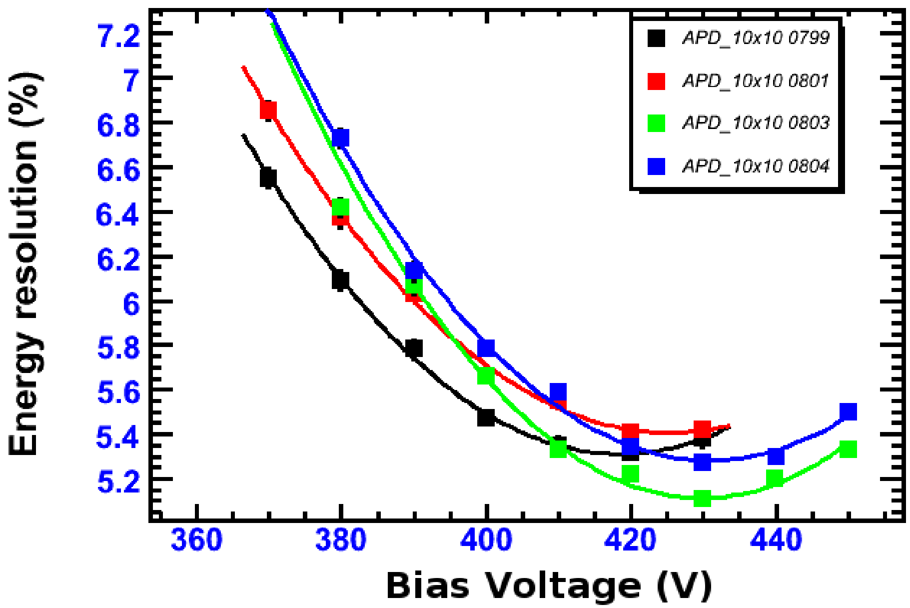


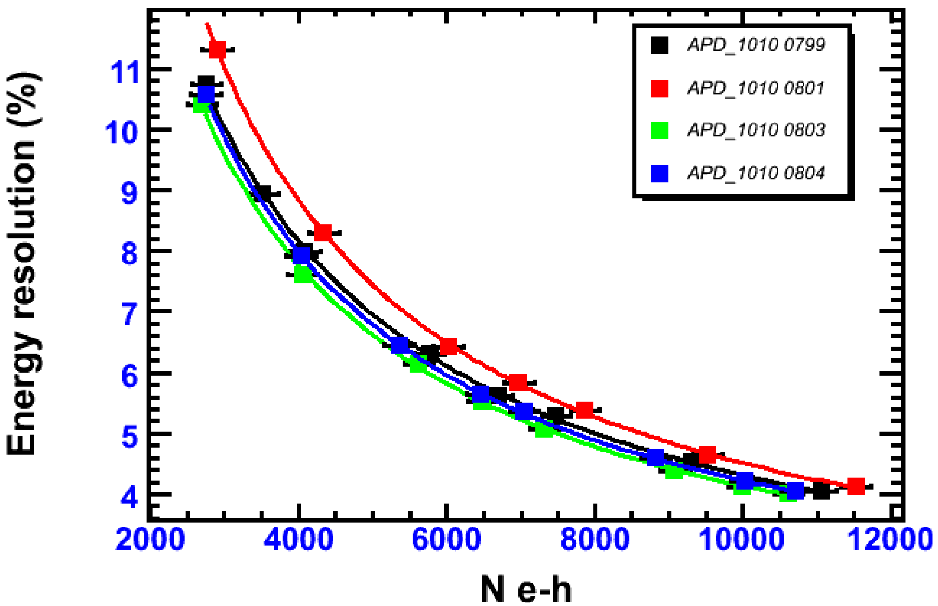
Characterization of APDs: light collection measurements



Some results (example for Hamamatsu S8664-1010)

- ✔ Amplitude spectra: 5.9 keV X-rays, light pulse and test pulse
- ✔ 5.9 keV corresponds to 1616 electron-hole pairs
- ✔ The number of e-h pairs produced by the LED pulse is obtained tunning the LED bias voltage.
- ✔ The higher the APD dark current, the worse the energy resolution
- ✔ Statistical contribution to the energy resolution obtained from the relation E.R. vs number of e-h pairs

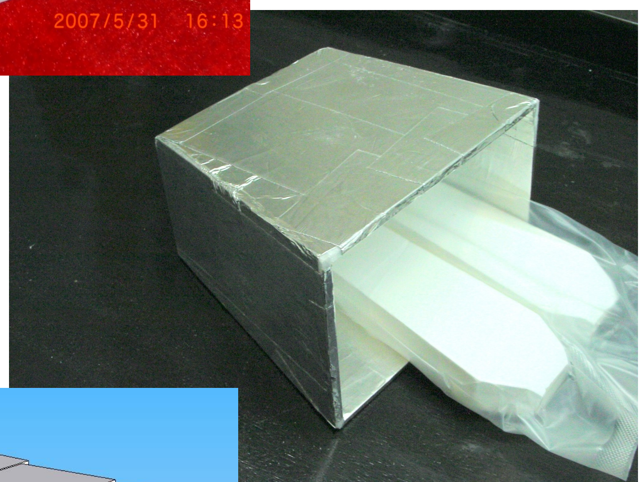


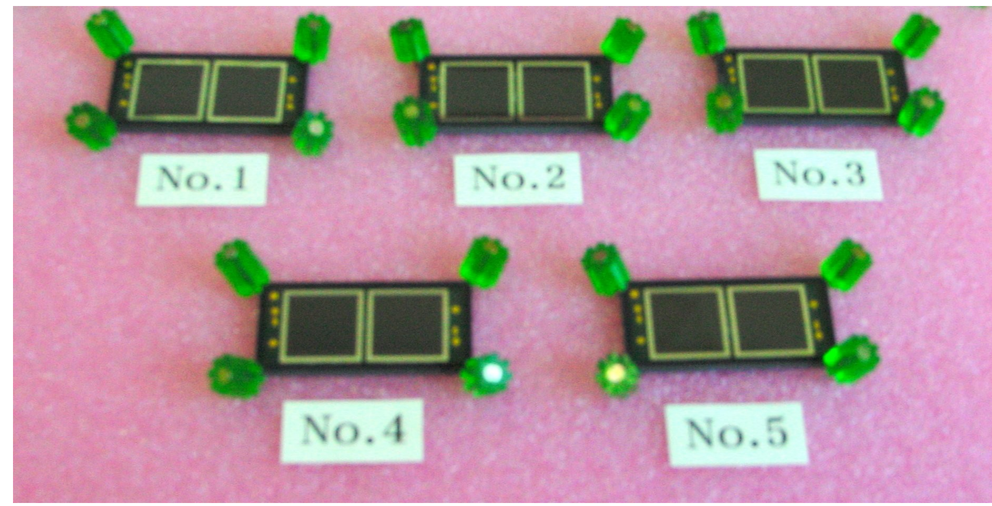


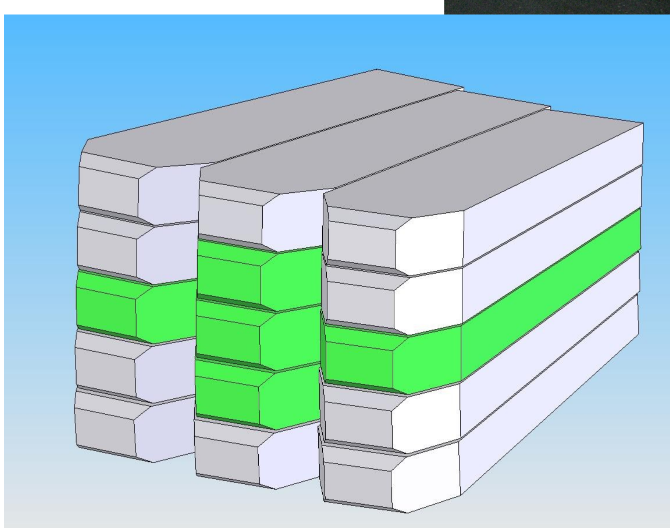
Tests with CsI(Tl) + APDs: prototype construction

Crystals from different providers have been obtained, ready for the tests:

- ✔ IMP Lanzou, China
- ✔ Hilger Crystals Ltd., England
- ✔ St. Gobain Crystals Inc., France
- ✔ Scionix, Netherlands







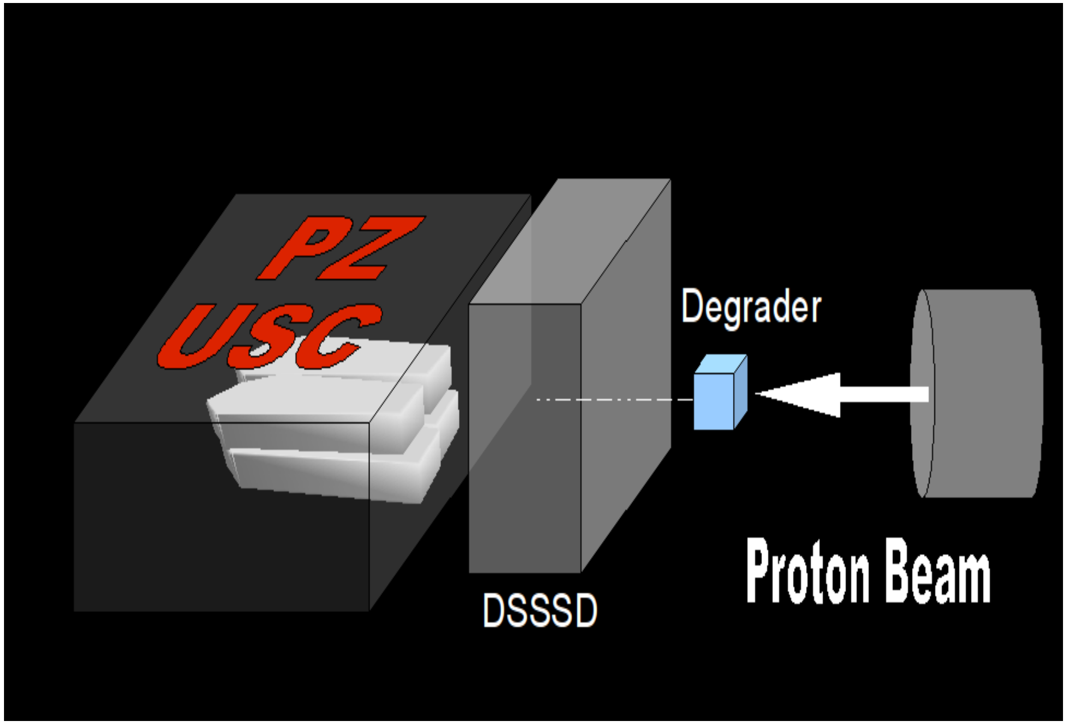
LAAPD development (Hamamatsu) based on S8664-1010 series:

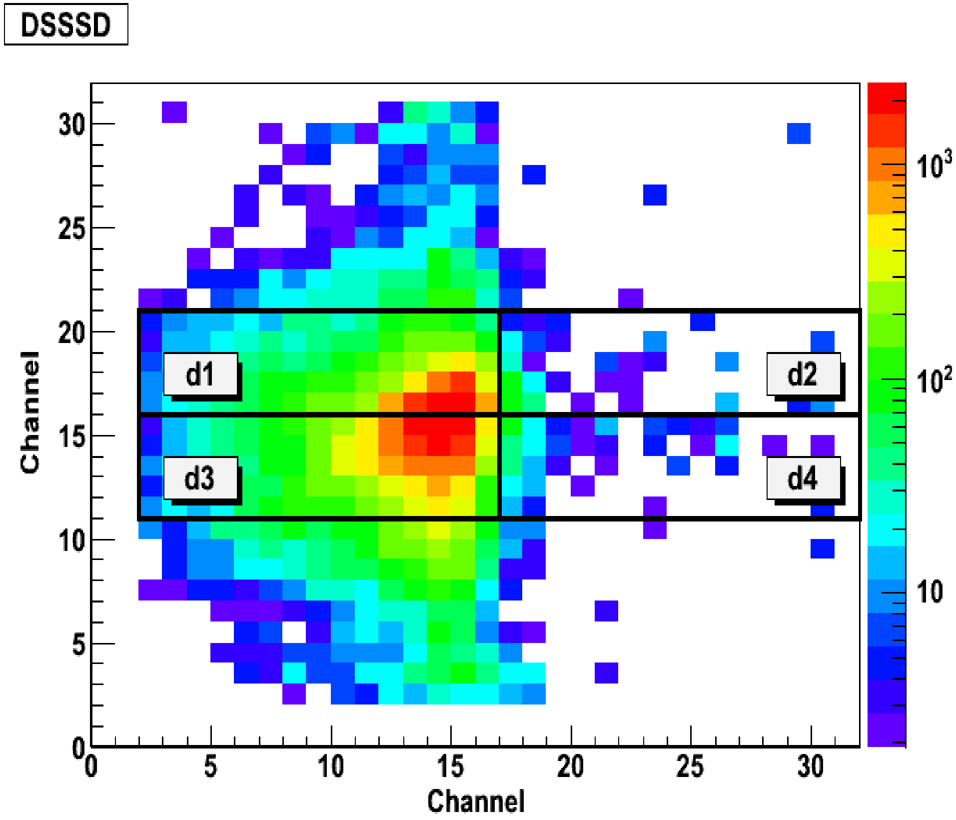
✔ First phase: double S8664-1010 sensor on a circuit, gap < 2 mm between sensors

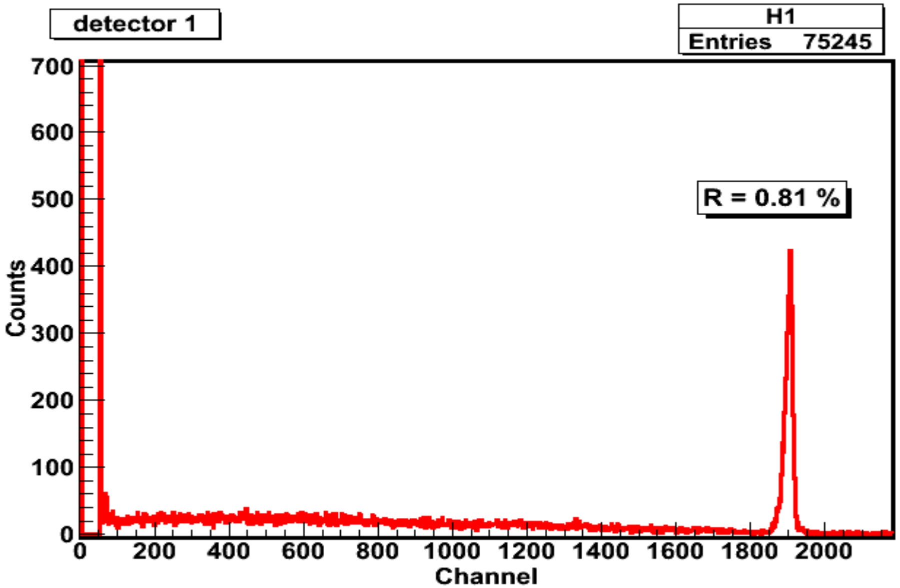
✔ Second phase: single 10x20 mm^2 sensor on ceramic mounting? Double sensor on a PCB or ceramic substrate? Other geometries? Alternatives?

✔ Ready prototype units (first phase) for immediate tests at TU-Darmstadt (tagged gammas up to 20 MeV, very good resolution), Madrid and Upssala (protons)

ProtoZero beam tests: protons (Upssala)







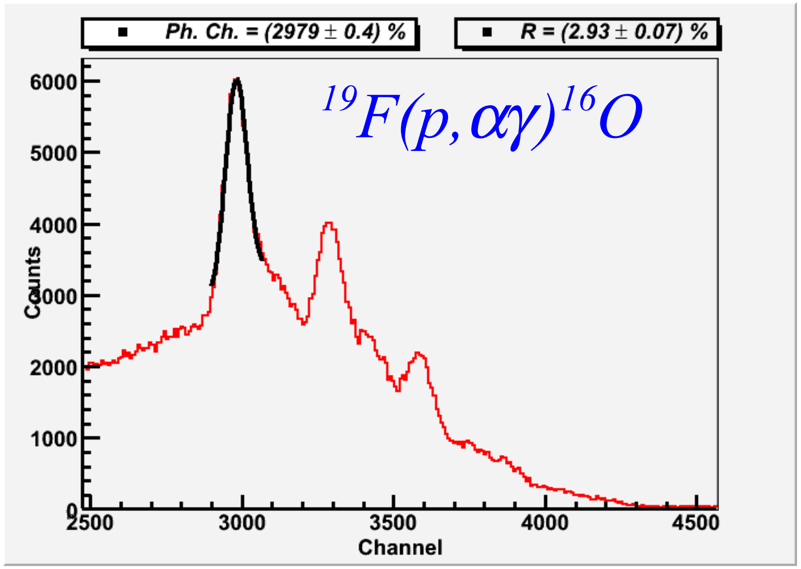
Protons @ 180 MeV in TSL-Upssala, Sweden:

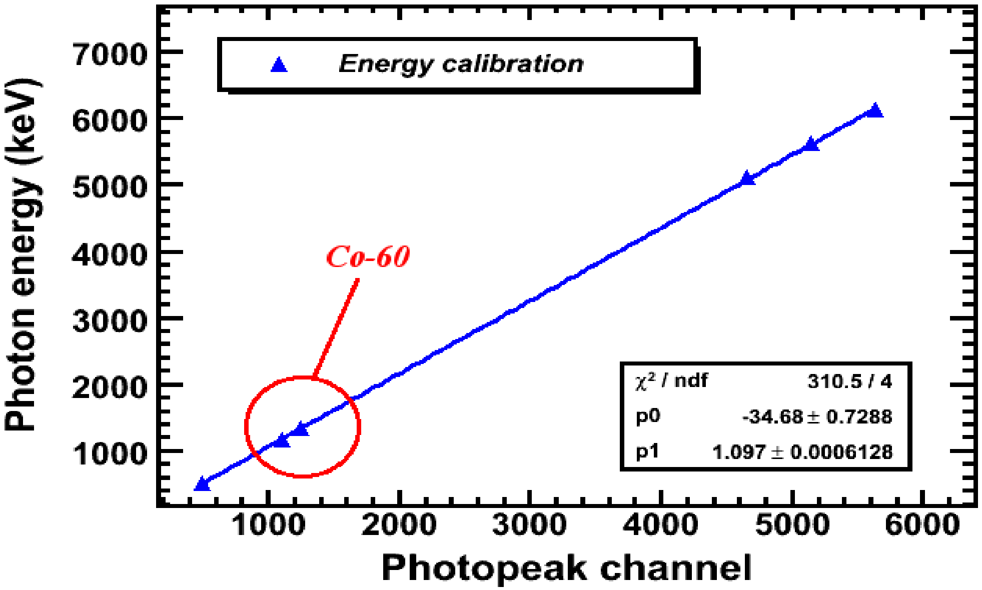
- ✔ Reduced ProtoZero model with 4 crystals around interaction point
- ✔ Setup not optimized for protons (reduced APD voltage)
- ✔ Energy resolution below 1% achieved in single crystals
- ✔ Addback studies ongoing: identified a clear problem with the wrapping thickness, reproductible in simulation

ProtoZero beam tests: gammas @ CMAM (Madrid)

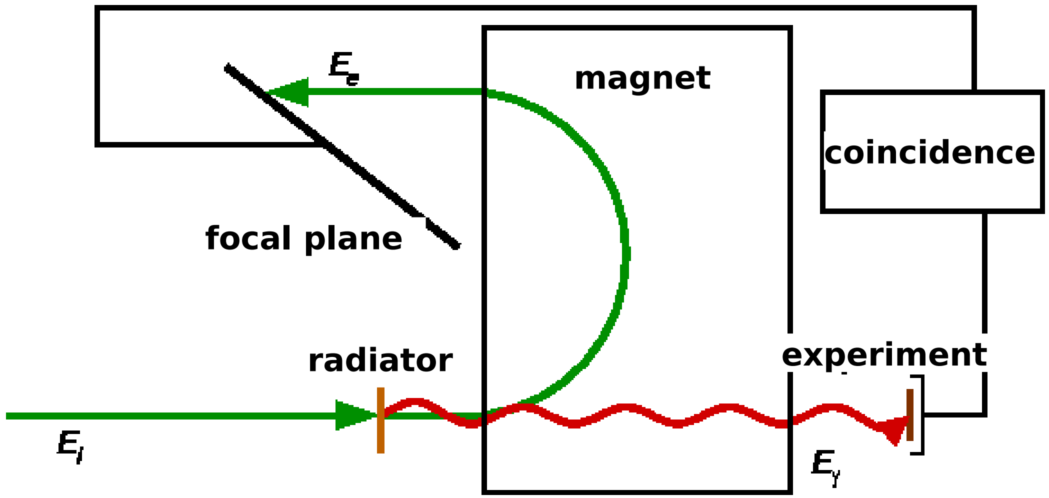
Gammas up to 6 MeV in CMAM-Madrid, Spain:

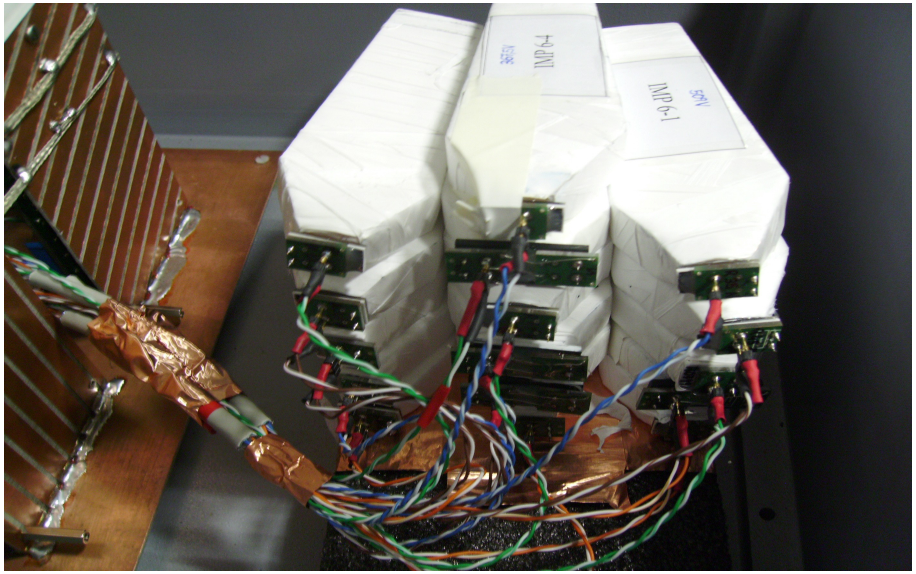
- ✔ Tests with different crystal providers
- ✔ Testing the electronic chain: full linearity up to 6 MeV
- ✔ Energy resolution below 1% achieved in single crystals
- ✔ First test of gammas addback techniques



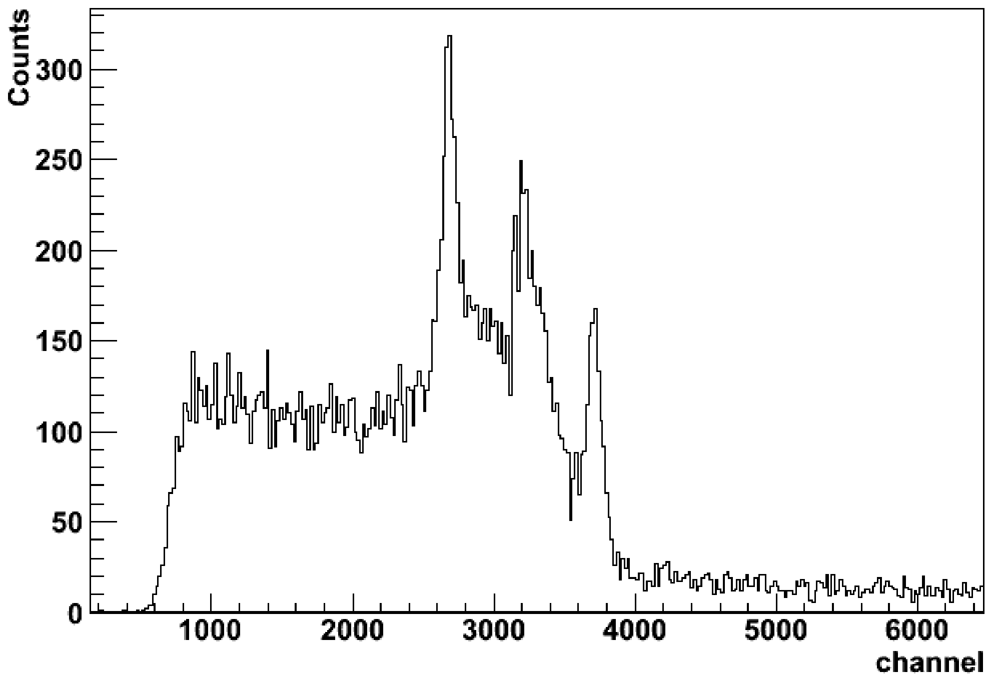


Beam tests: gammas at TUD-Darmstadt





Cut spectrum of the ADC center CsI



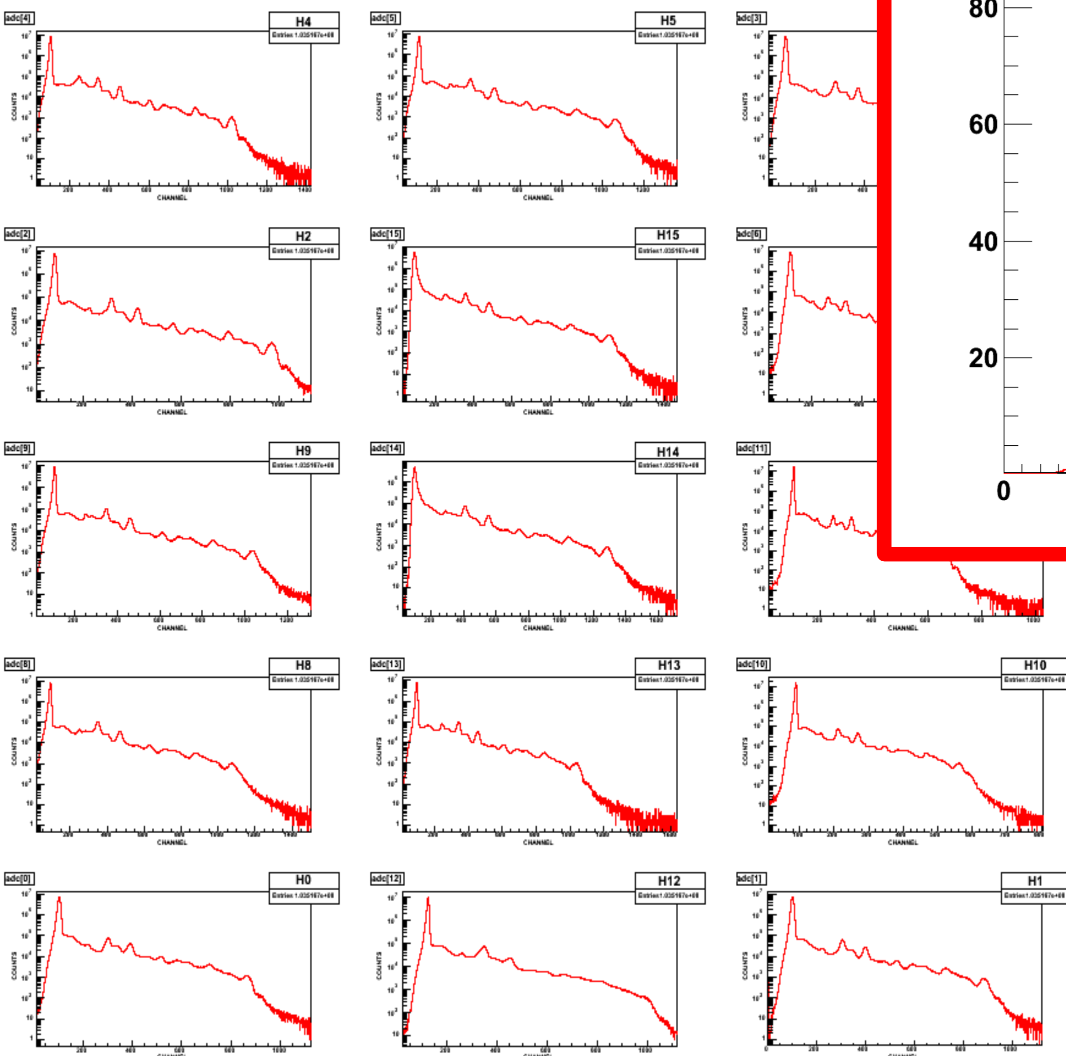
Features of the high-resolution tagger @ TUD-Darmstadt, Germany:

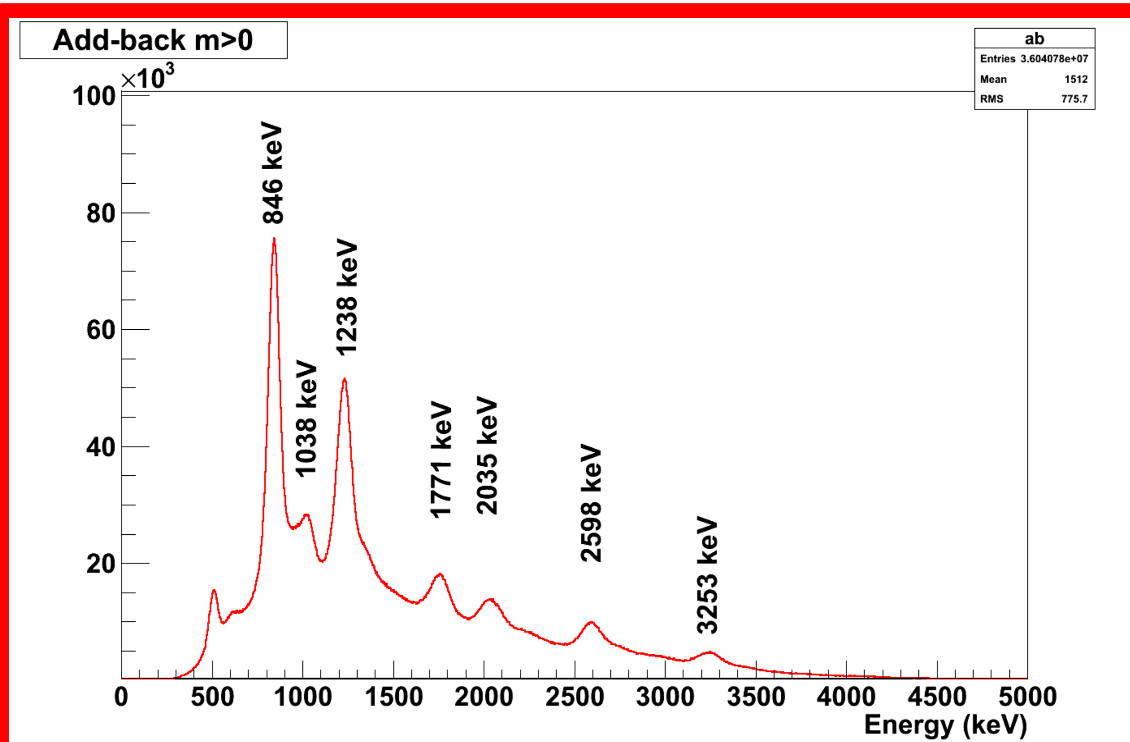
- ✔ Energy range: 6 MeV $\leq E_\gamma \leq$ 20 MeV
- ✔ Energy resolution: ΔE = 25 keV @ 10 MeV
- ✔ Energy window: ~3 MeV
- ✔ Photon intensity: ~ 10^4 keV^{-1}s^{-1}

Online spectra @ 10 MeV (ongoing study)

- ✔ Full ProtoZero setup (16 CsI[Tl] crystals) with APD
- ✔ Mesytec preamps and amplifiers, standard elec. chain
- ✔ Temperature and HV monitoring implemented

Beam tests: gammas add-back with Co-56





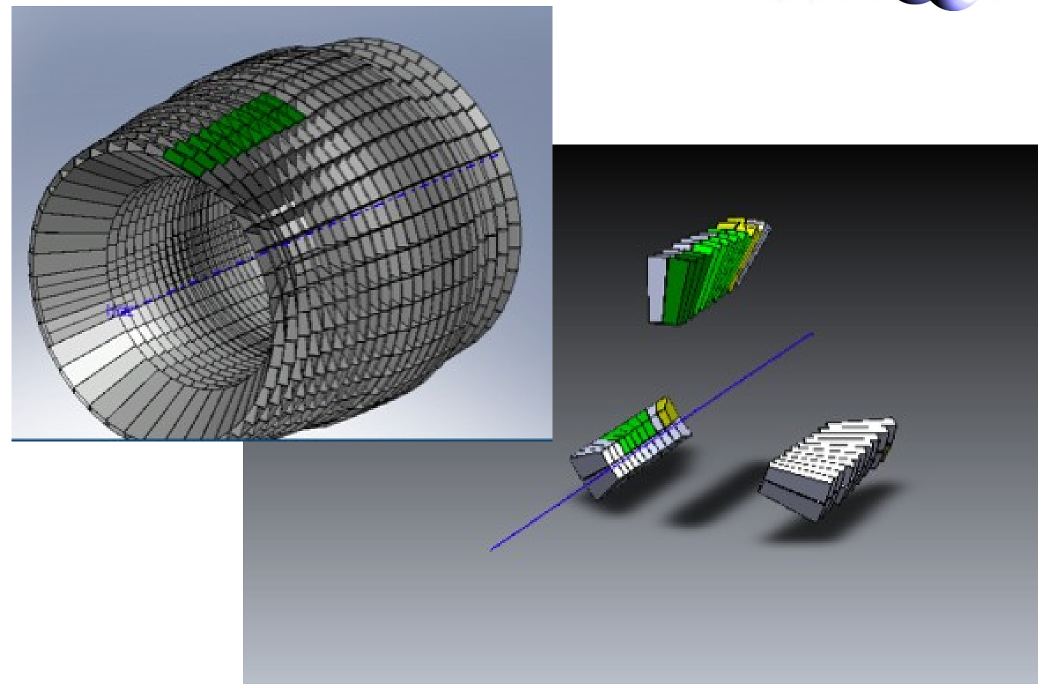
Calibration runs with Co-56

- ✔ Add-back reconstruction works quite well!
- ✔ Energy resolution values after add-back comparable with individual crystals values

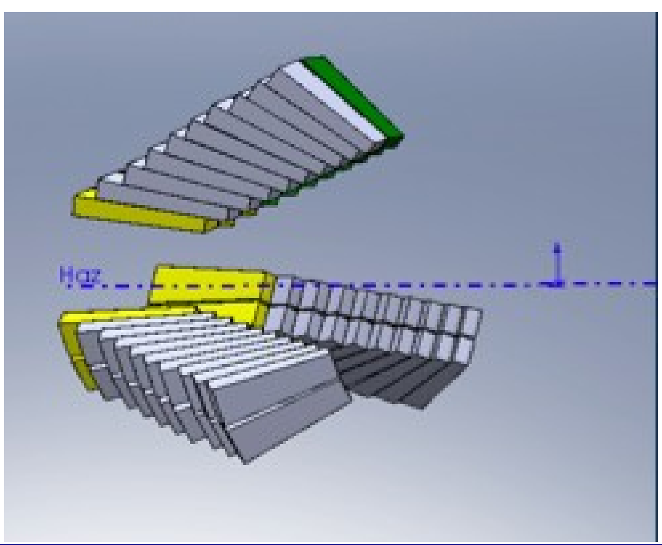
Prototypes, ProtoDemo (DemoZero?) and Demonstrator

Demonstrator concept

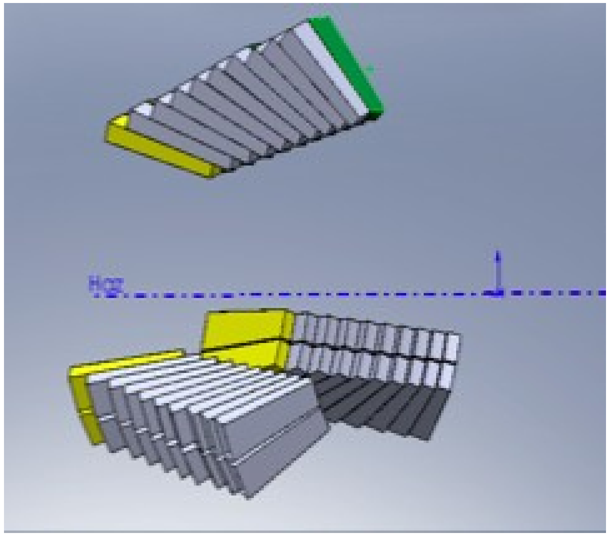
- ✔ Based on “petals”, each one covering a small azimuthal portion, making possible the extension to lower polar angles.
- ✔ 20 alveoli per petal for a total of 80 crystals,
- ✔ Petals contribution from different collaborators within R^3B.
- ✔ Polar range: ~ 32º to 65º (in nominal position).
- ✔ Mechanics allow three different positioning for different experiments. Different number of petals allowed.



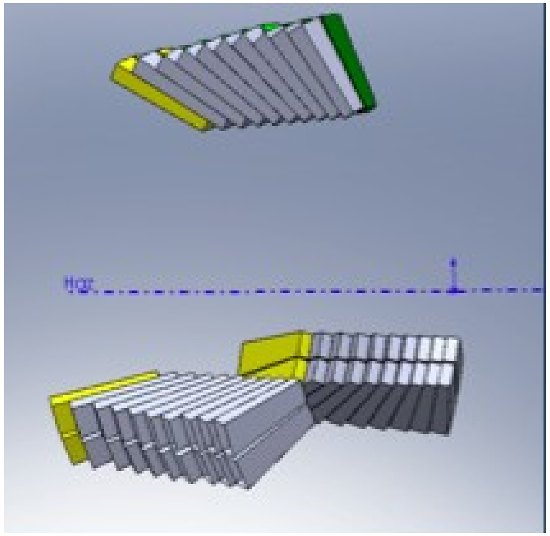
10 degrees



20 degrees



nominal position



Outlook and timetable

Outlook:

- CALIFA, multipurpose calorimeter-espectrometer for R^3B especifications.
- Tests on lab and beam lines (protons and gammas) shows promising results.

Timetible (as we would like...):

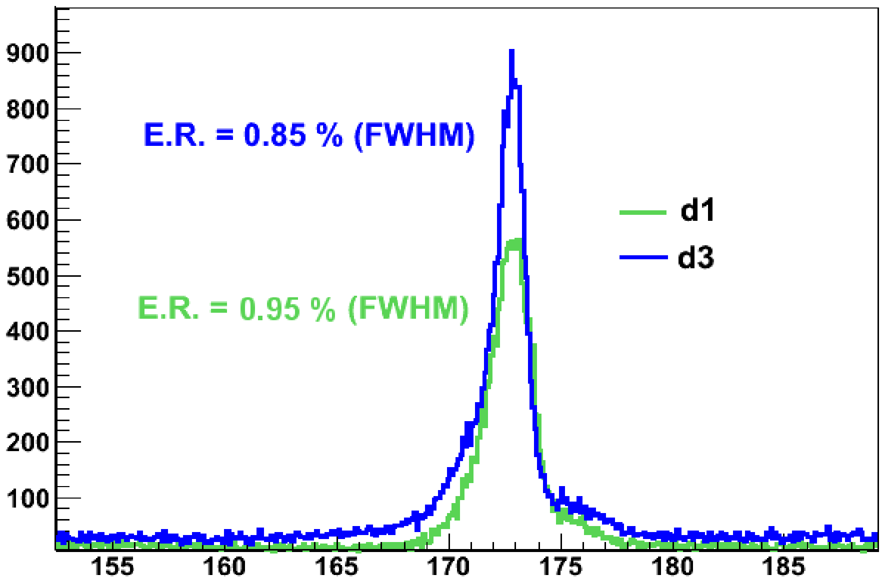
Demonstrator (2011-2012):

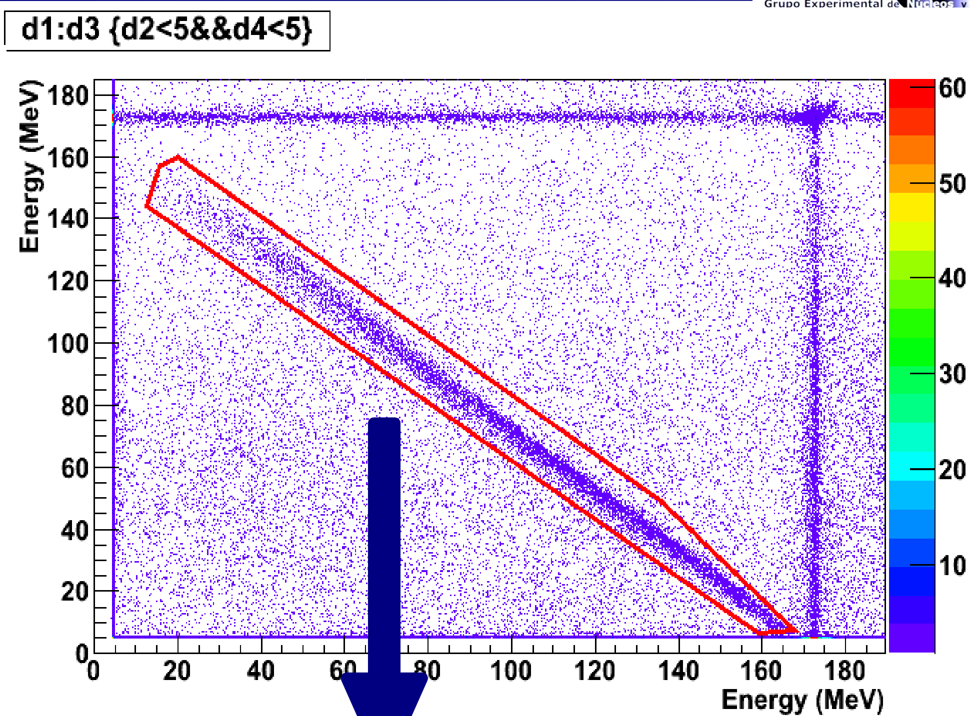
- Completion of first 32 crystals (DemoZero) around November 2010
- Decision about final crystal types, mechanics,... for demostrator before 2nd quarter 2011

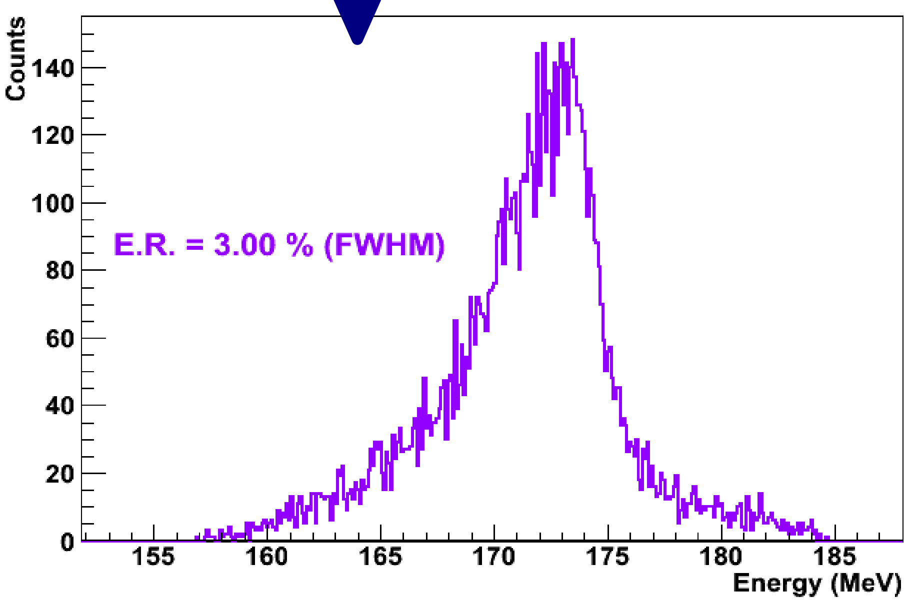
TDR for Barrel in 2011, construction phase should begin in 2012.

Thank you very much for your attention!

ProtoZero beam tests: protons (Upssala)



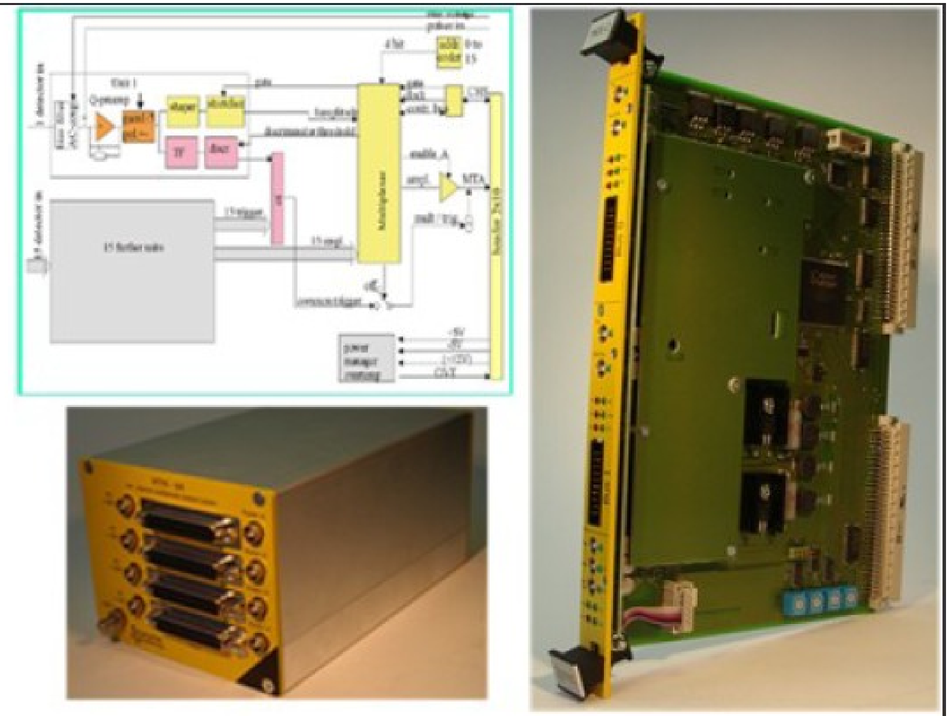




Electronics solution

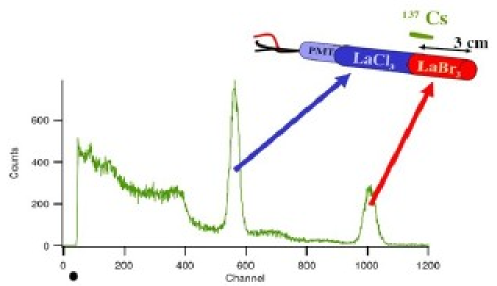
Electronics:

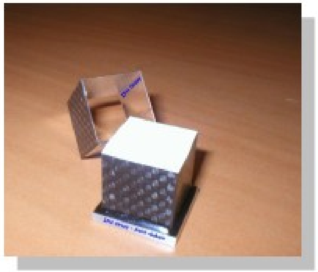
- Mesytec development MPR16-B.
- Include Temperature/voltage compensation.
- Already available, working on the dynamical range
- Other options (digital, based on HADES ADC+FPGA, analog, EURONS analog multiplexer readout) open



Status on CRYSTALS for the Forwardendcap

First results with phoswich configuration





LaCl/LaBr performs nicely but there are still many aspects to investigate

- new prototype under negotiation with Saint Gobain
- Evaluate with GEANT 4 the misidentification of p using long crystals (both inelastic and add-back)
- EVALUATE THE RATIO of events in the 180 MeV peak in the phoswich identification plot
- IS POSSIBLE to work with PM in the phoswich configuration?

Chalmers contribution

PARIS collaboration have built a phoswich CsI(NaI)+ LaCl

GET IN CONTACT and learn from their experience

ALTERNATIVE Test response of long CsI crystals for the forward angles