Novel scintillator arrays

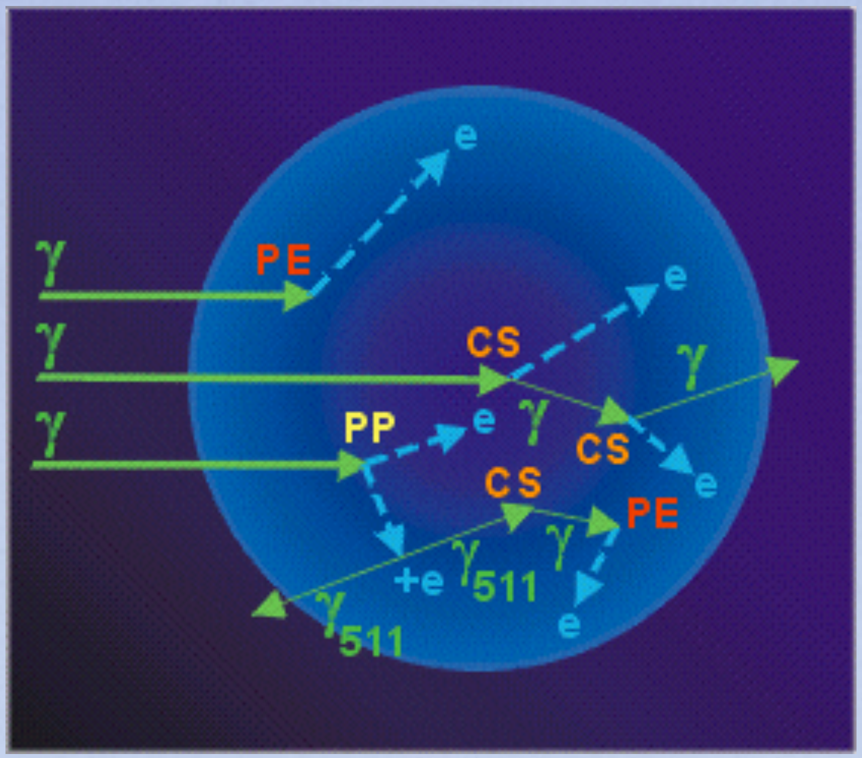
David Jenkins

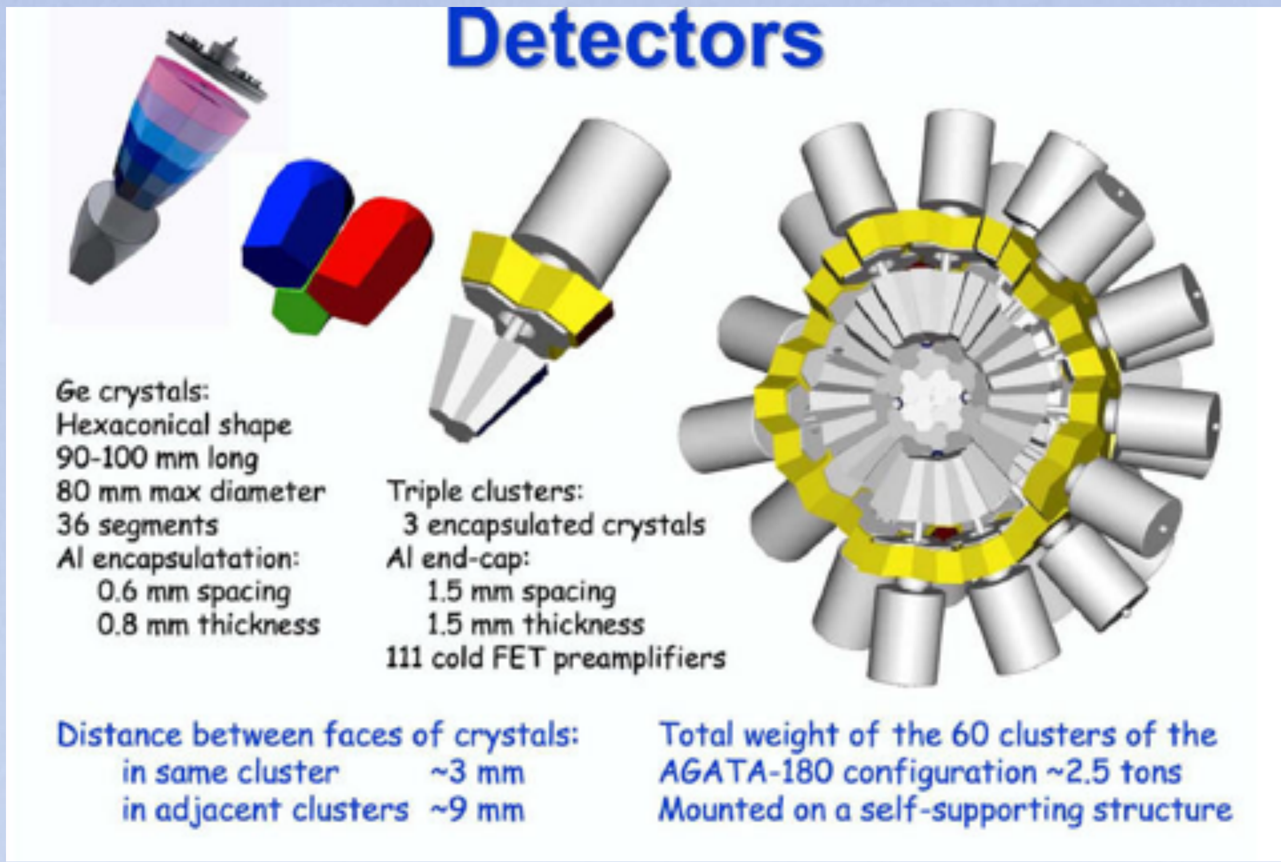
USIAS
University of Strasbourg
Institute for Advanced Study

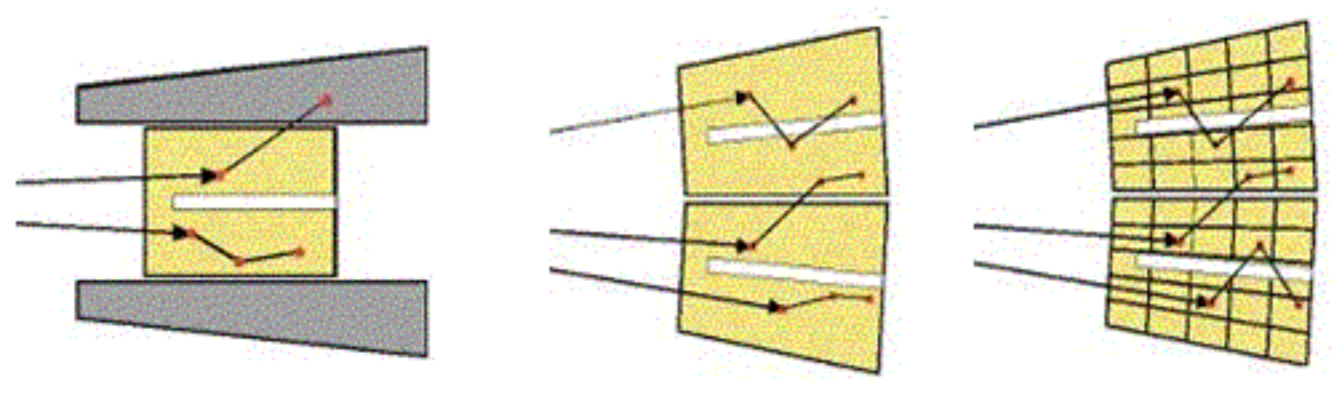
UNIVERSITY of York

with thanks to Franco Camera, Oli Roberts, Giulia Hull,
Roman Gernhaeuser, Paul Davies
Funding from NuPNET GANAS, STFC and TSB

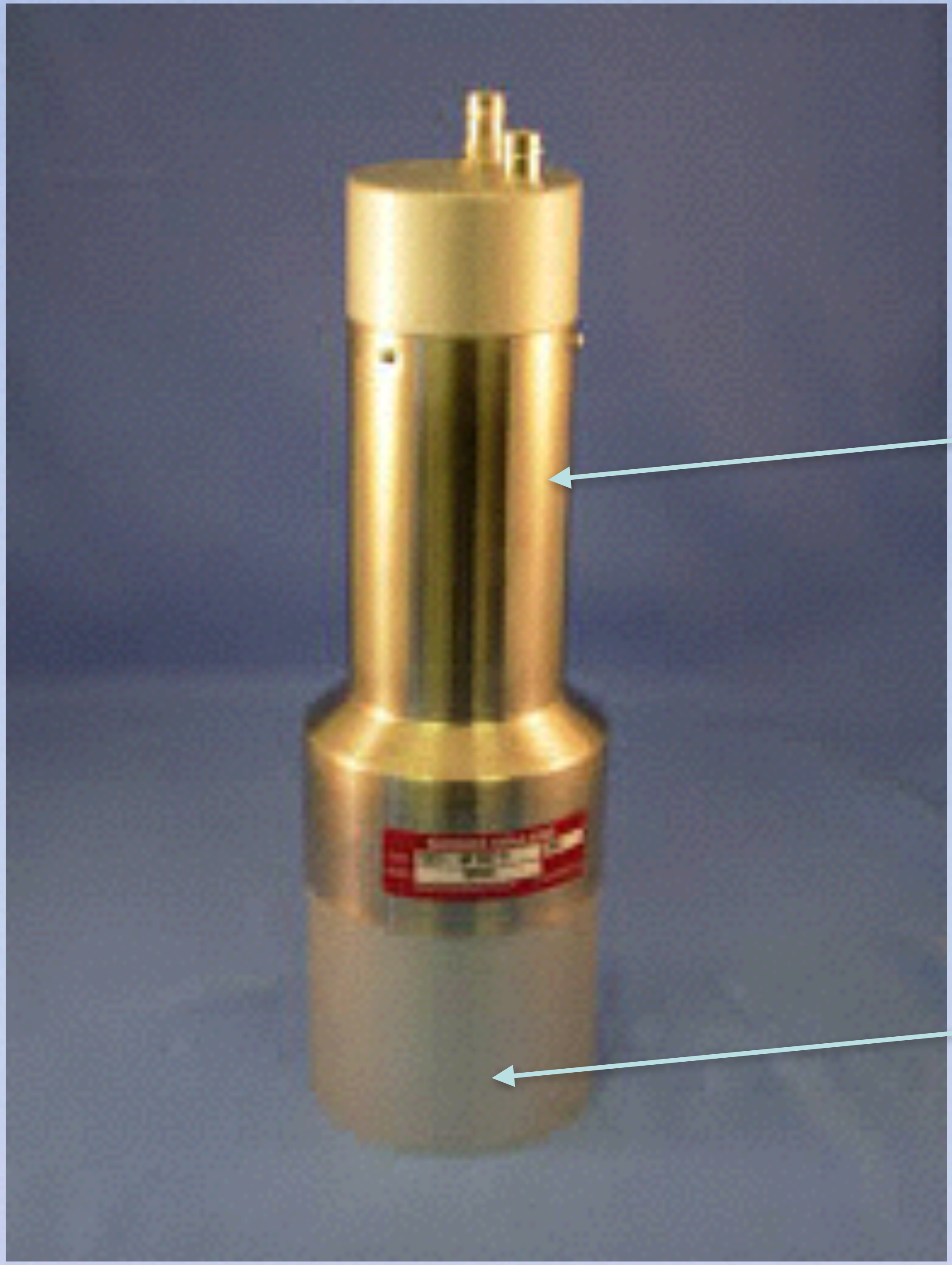
State of the art: Gamma-ray tracking





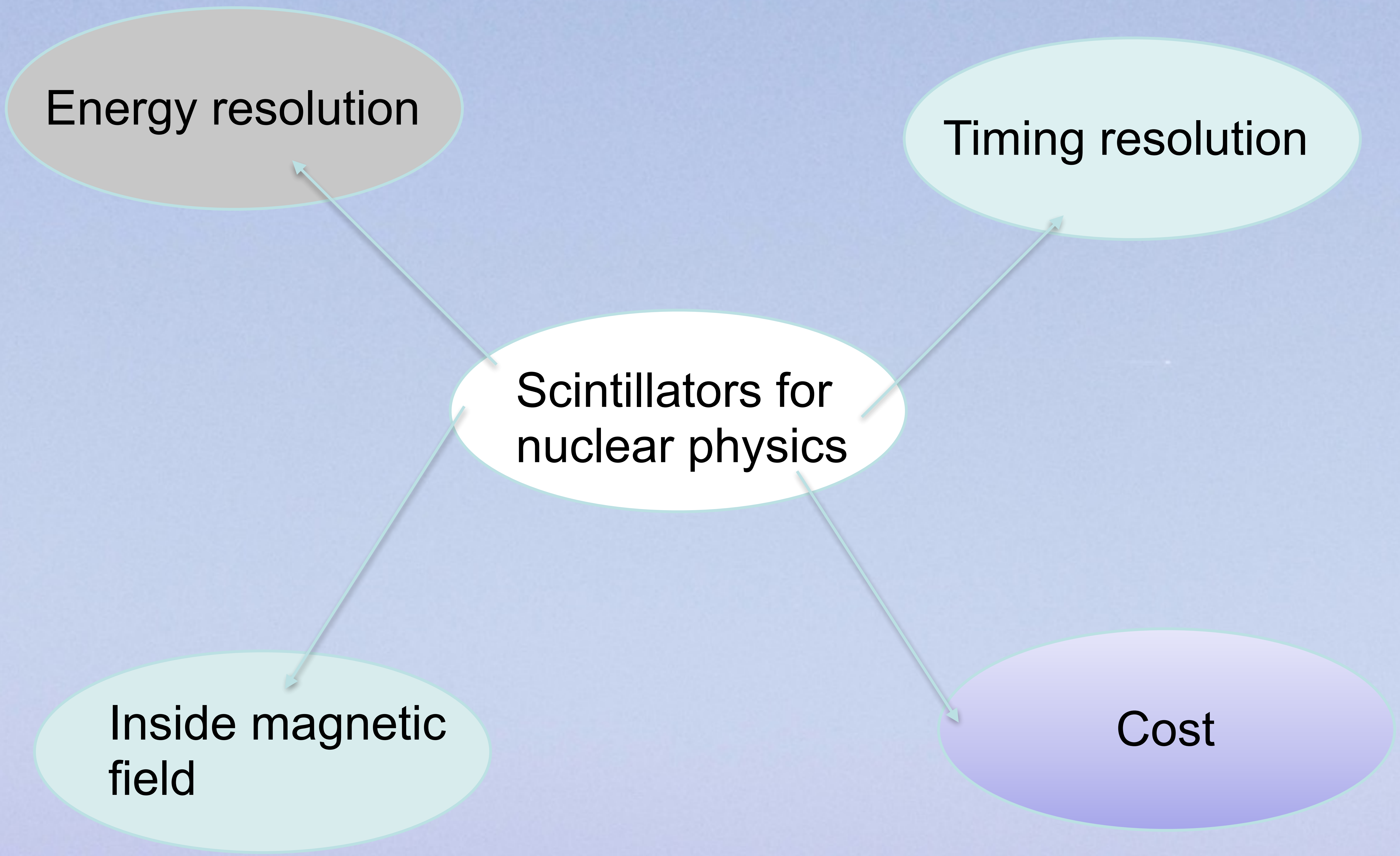


Typical scintillation detector

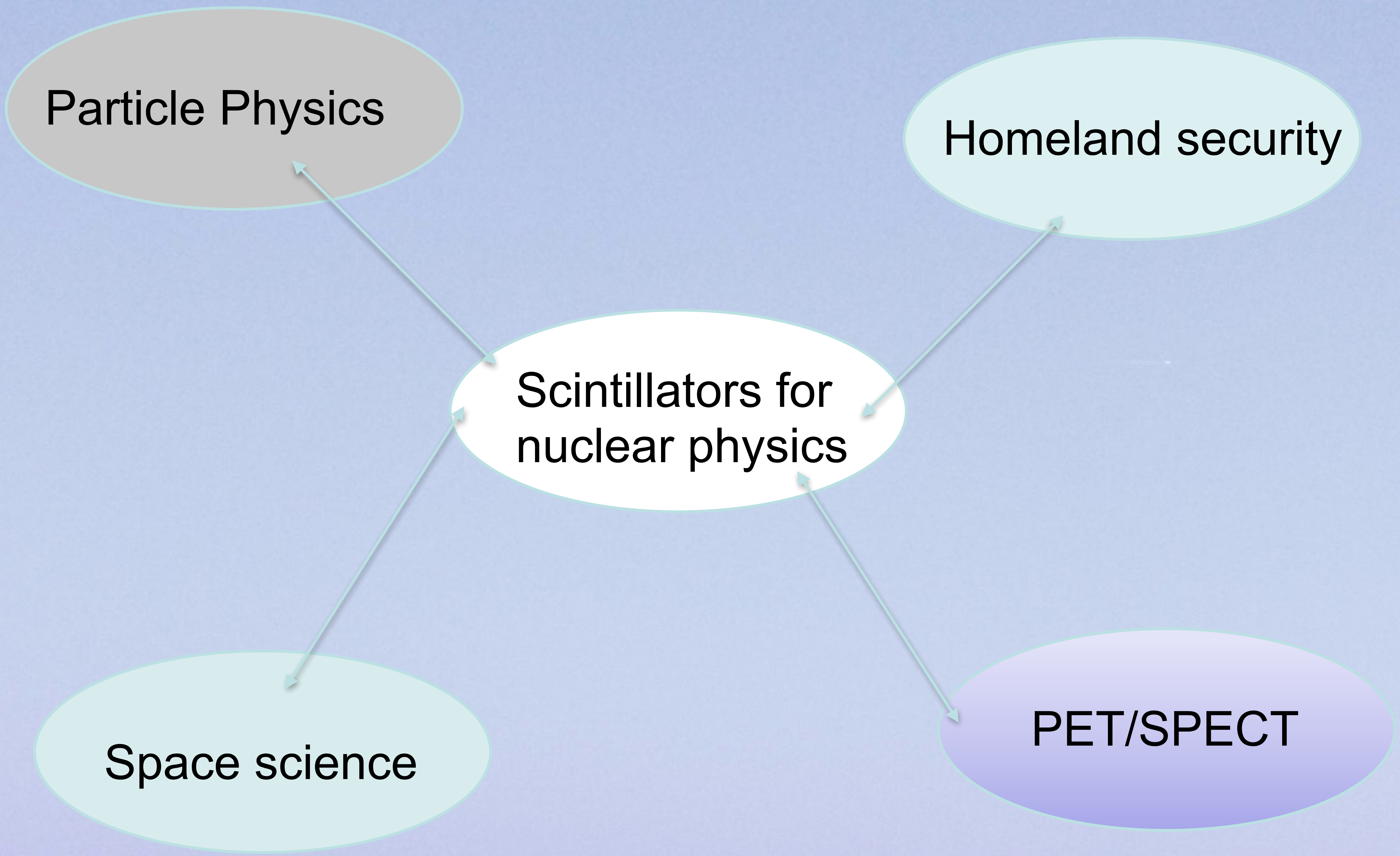


PMT - fragile, needs HV but low noise, well-established technology

Sodium iodide - best resolution ~ 7%
Hygroscopic
Relatively low cost



Energy resolution
Timing resolution
Scintillators for nuclear physics
Inside magnetic field
Cost


Particle Physics
Homeland security
Scintillators for nuclear physics
Space science
PET/SPECT

New scintillators

First Generation scintillators

NaI(Tl): energy resolution of 7% at 662 keV, strong non linearity, bad time resolution
BaF_2: bad energy resolution, excellent time resolution
BGO: bad energy resolution, bad time resolution, excellent efficiency
CsI(Tl): good for the measurement of light charged particles

Second Generation scintillators

Lanthanum Halide: **$LaBr_3$:Ce, $LaCl_3$:Ce**
New Materials: **SrI_2:Eu, $CeBr_3$**
Elpasolide : **CLYC:Ce, CLLB:Ce, CLLC:Ce**
Ceramic: **GYGAG:Ce**

Material	Light Yield [ph/MeV]	Emission λ_{max} [nm]	En. Res. at 662 keV [%]	Density [g/cm^2]	Pricipal decay time [ns]
NaI:Tl	38000	415	6-7	3.7	230
CsI:Tl	52000	540	6-7	4.5	1000
$LaBr_3$:Ce	63000	360	3	5.1	17
SrI_2:Eu	80000	480	3-4	4.6	1500
$CeBr_3$	45000	370	<5%	5.2	17
GYGAG:Ce	40000	540	<5%	5.8	250
CLYC:Ce	20000	390	4	3.3	1 CVL 50, ~1000

Properties of new scintillators: SrI_2, $CeBr_3$, GYGAG

SrI_2

- Slow scintillator (decay time ~1.5μs)
- Self absorption
- Excellent energy res. (< 3-4% @ 662 keV)
- It is available on the market

$CeBr_3$

- It can be seen as a 100% doped $LaBr_3$:Ce
- Fast scintillator (< 1ns time resolution as $LaBr_3$:Ce)
- Good Energy resolution (< 5% @ 662 keV)
- No internal radiation
- It is available up to 3″x3″ on the market
- CoDoping developed in prototypes

GYGAG

- $Gd_{1.5}Y_{1.5}Ga_{2.2}Al_{1.8}O_{12}$:Ce - Polycrystalline ceramic scintillators
- Density and effective Z of GYGAG are 5.8 g/cm^3 and 48
- Very few samples available
- Good Energy resolution (< 5% @ 662 keV)
- Fast scintillator (decay time ~ 250 ns)

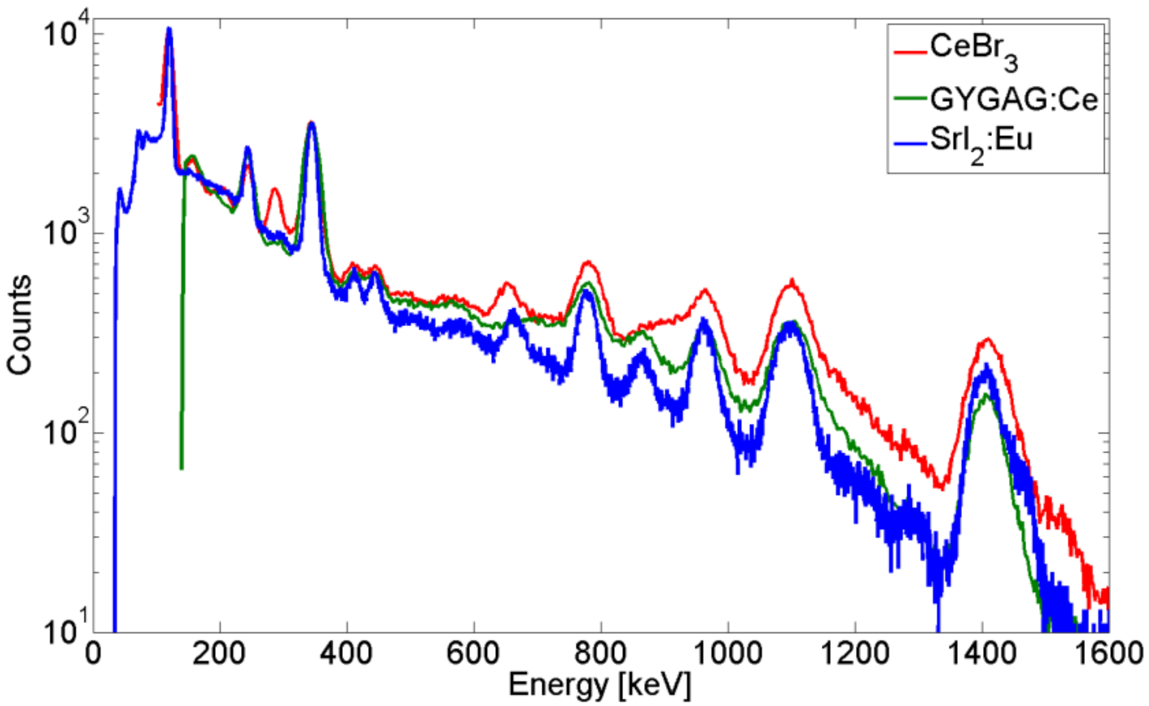
Measurements with SrI_2, $CeBr_3$, GYGAG

Detectors from Livermore and IPN Orsay:

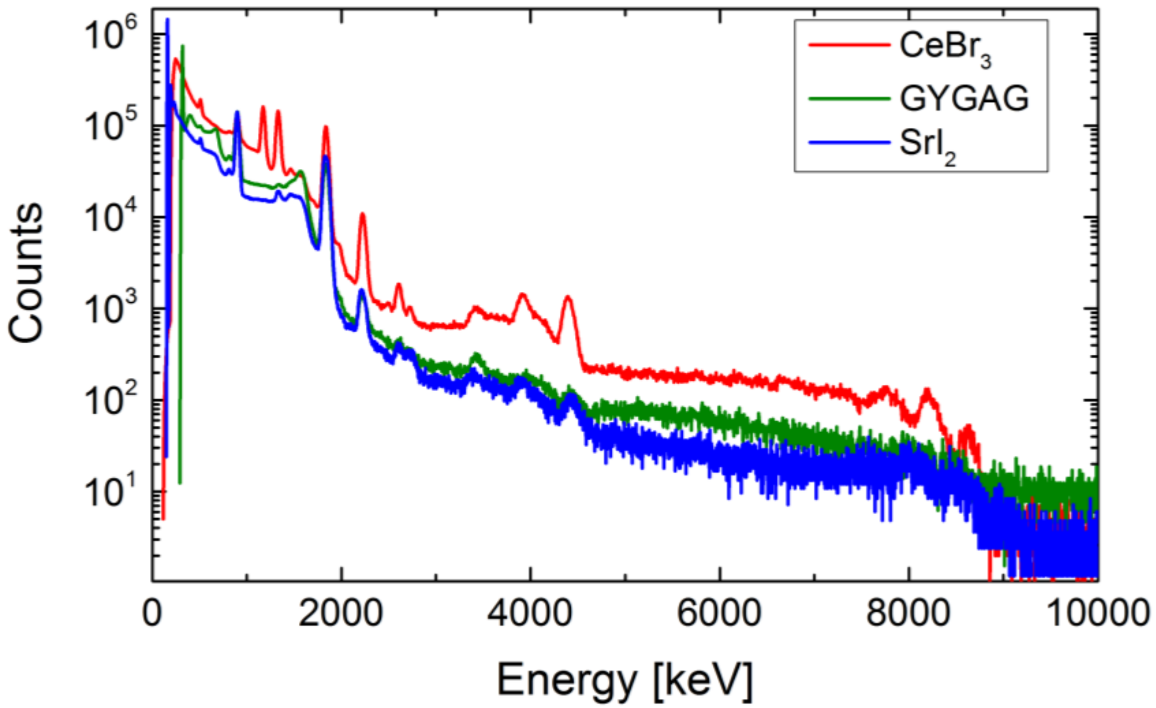
- Cylindrical 2″ x 2″ SrI_2
- Cylindrical 2″ x 3″ $CeBr_3$
- Cylindrical 0.3″ x 2″ GYGAG

Measurements performed in Milan:

- The crystals were **scanned** using a collimated beam of 662 keV gamma rays (along the three axes).
- Crystal response was measured using standard sources (^{60}Co, ^{88}Y, ^{137}Cs, ^{152}Eu)
- The crystal response of gamma rays was measured at **4.4 MeV and 9 MeV**.
- **Pulses up to 9 MeV** gamma rays were digitized.



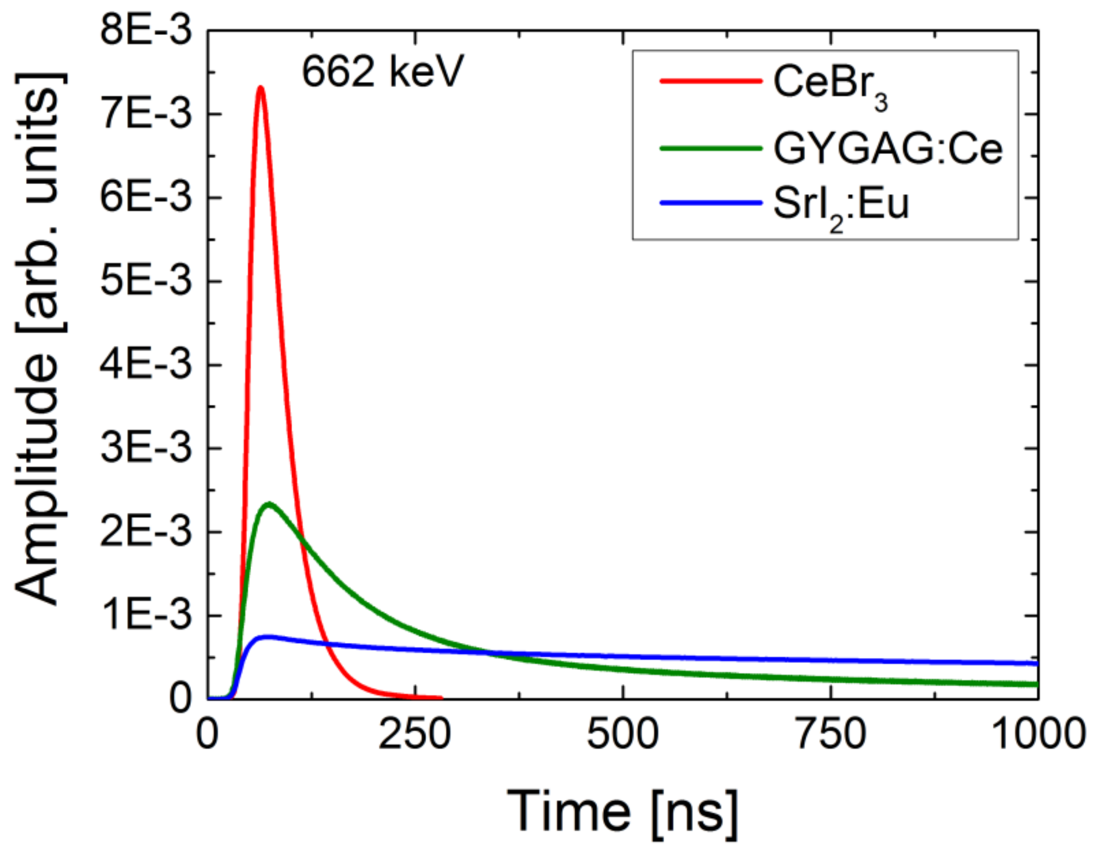
Acquired spectra with a ^{152}Eu and AmBe(Ni) sources

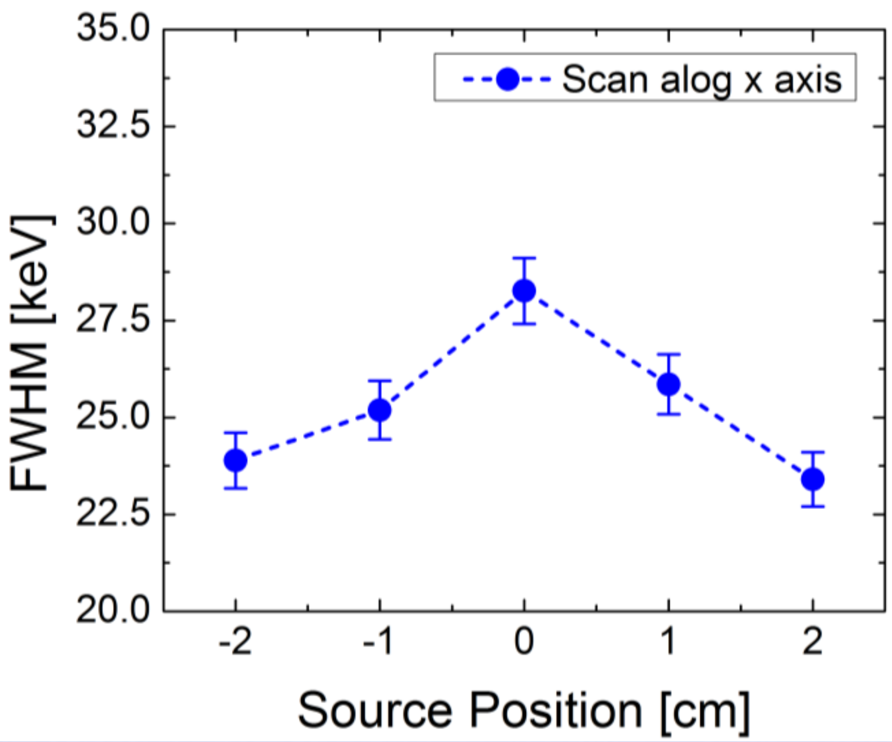


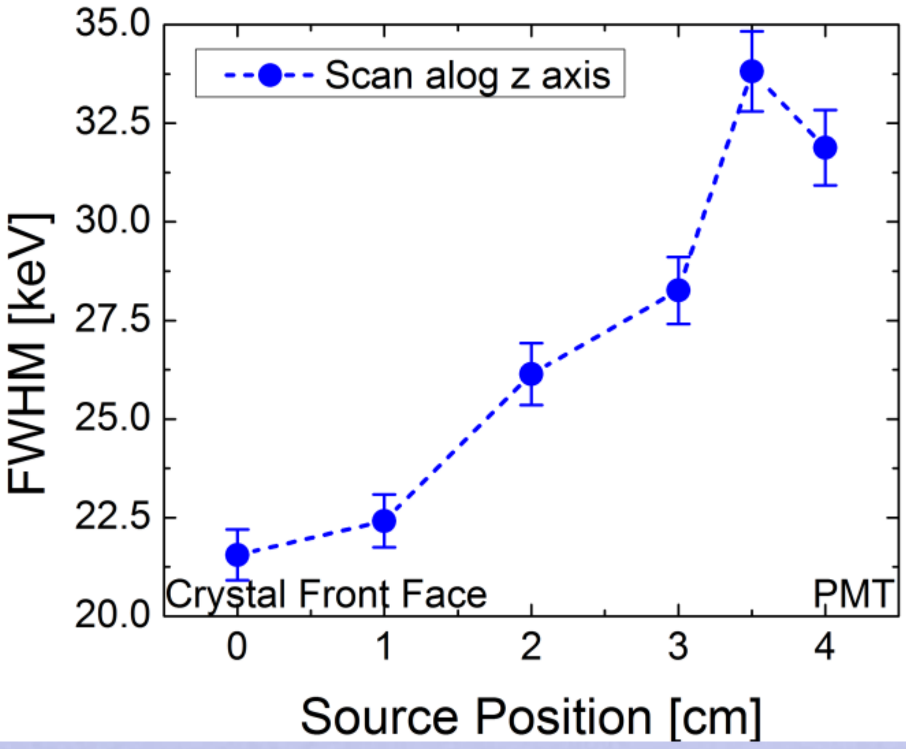
Pulses and scan: SrI_2, $CeBr_3$, GYGAG

The pulses (**up to 9MeV**) were digitized using a Le Croy 12 bit 500 MHz oscilloscope.
No significant change in shape was observed in **GYGAG:Ce** and **SrI_2:Eu** going from low to high energy.
A small variation was seen in **$CeBr_3$** at high energy (9 MeV).

Detector	Rise Time [ns]	Fall Time [ns]
CeBr3	18	67
GYGAG:Ce	27	700
SrI2:Eu	24	7000





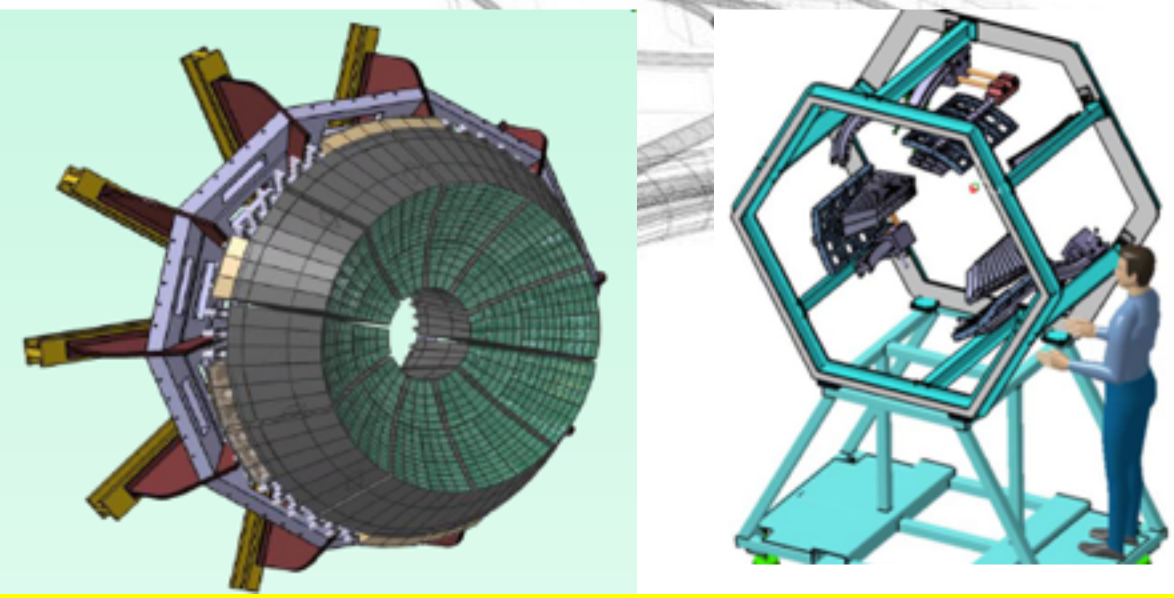


The centroid position and FWHM slightly change with the position of the source in $CeBr_3$ and GYGAG, while they change in **SrI_2 due to the self absorption.**

Topical examples of arrays

CALIFA forward endcap

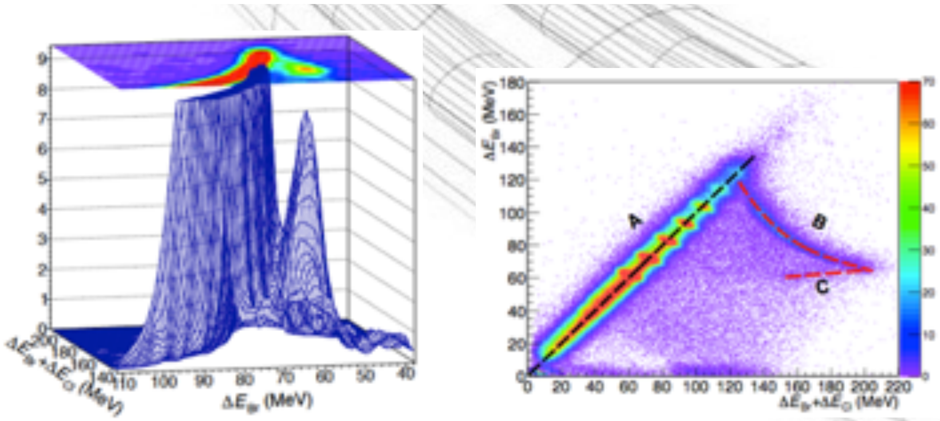
- On our way to CALIFA forward endcap…

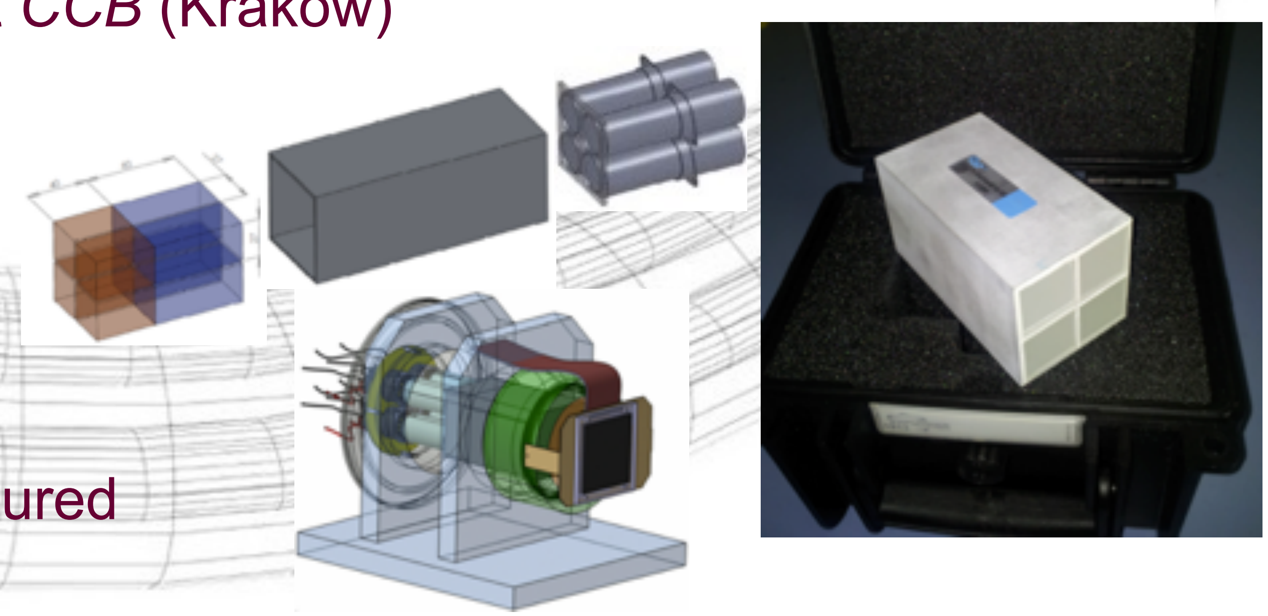


N of crystals	750
Crystal geom.	15
Tot. Crystal Volume/ weight	110000 cm^3 / 560 kg

CEPA: CALIFA Endcap Phoswich Array

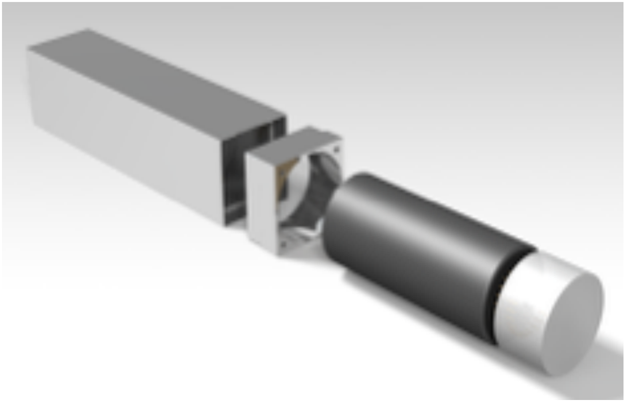
- Phoswich concept: 2 scintillator crystals coupled with a common readout. They must be optically compatible (LaBr3-LaCl3). It allows for E - ΔE use (telescope for high-E protons)
- Prototyping: CEPA4. Tested with high-E protons at *CCB* (Krakow)





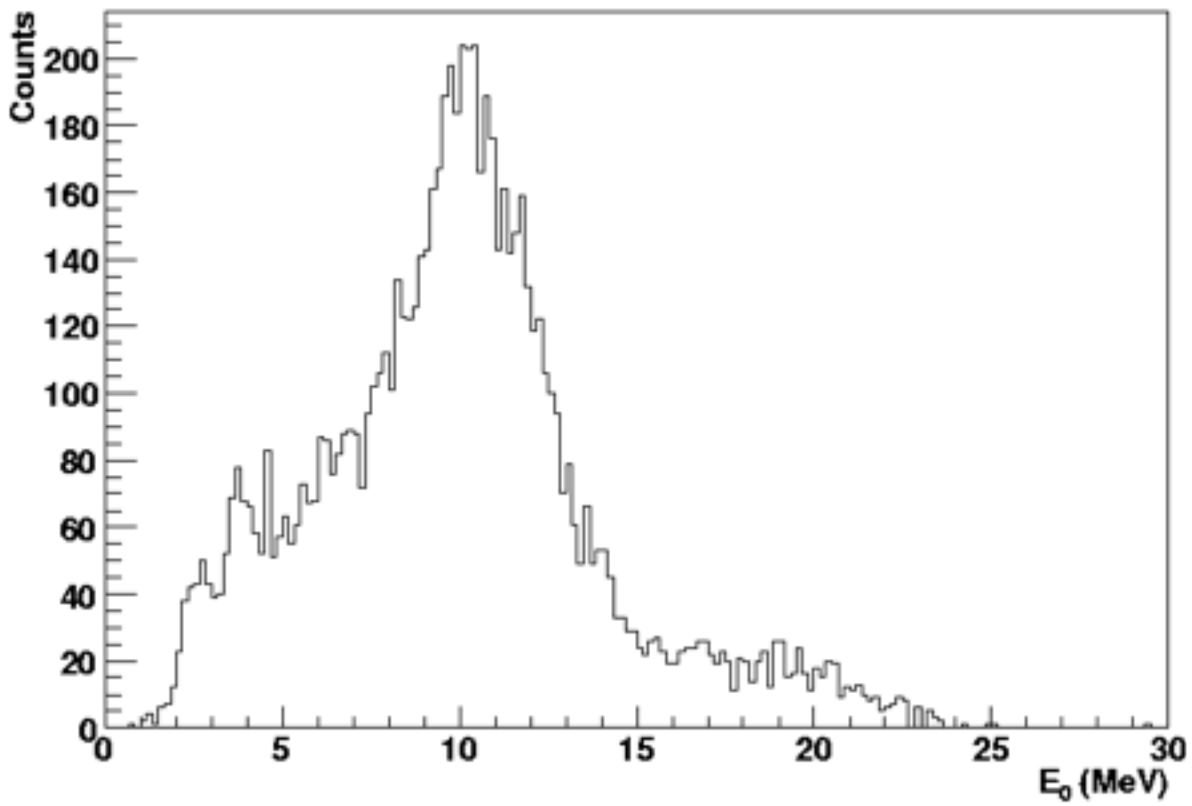
- Proton energies beyond total punch-through measured for the first time (220 & 230 MeV)

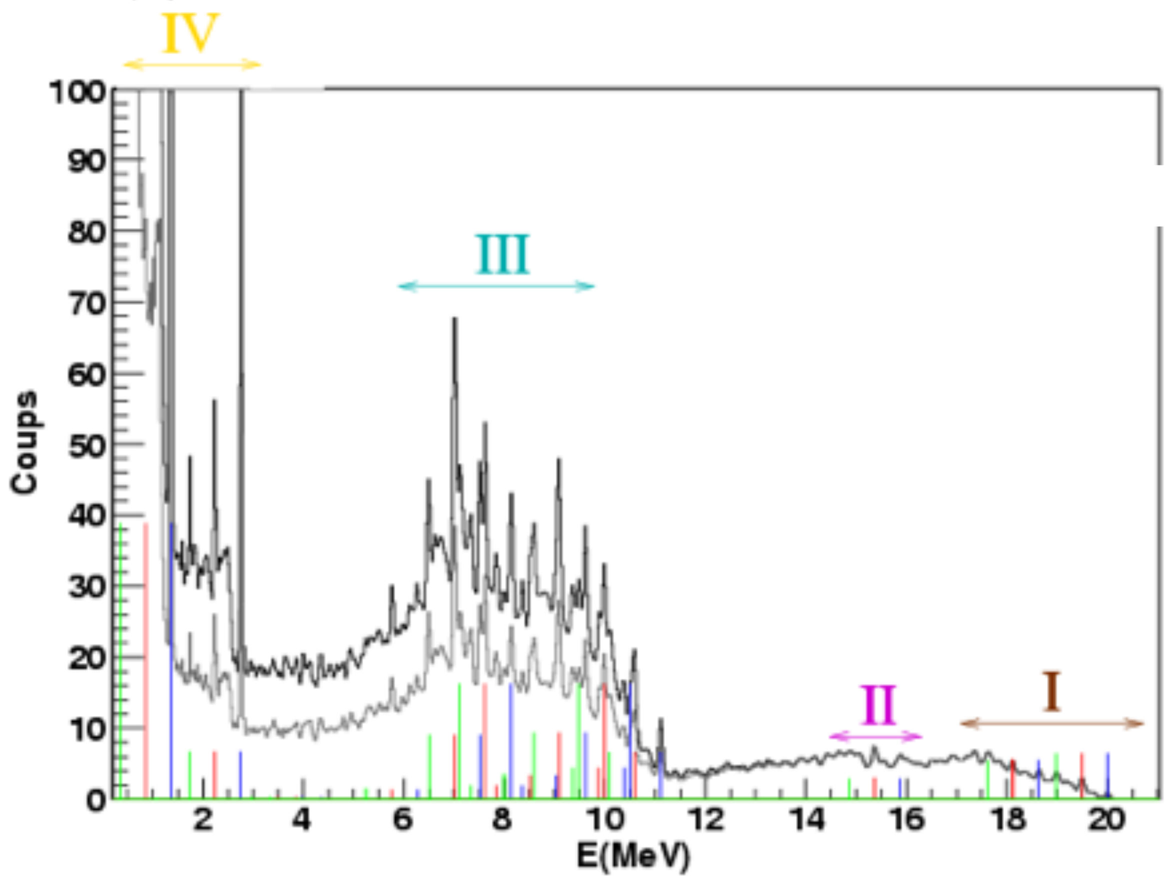
PARIS



PARIS (Photon Array for studies with radioactive Ions and Stable beams), a detector for the future, based on new $LaBr_3$ scintillating crystals (43 laboratories involved)

A much better efficiency/resolution

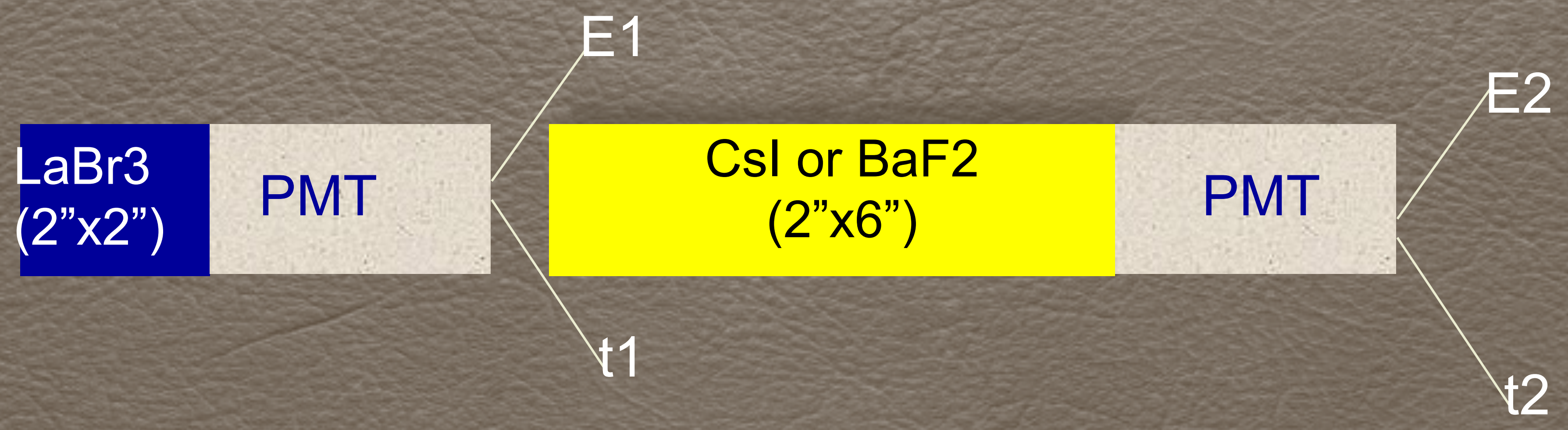




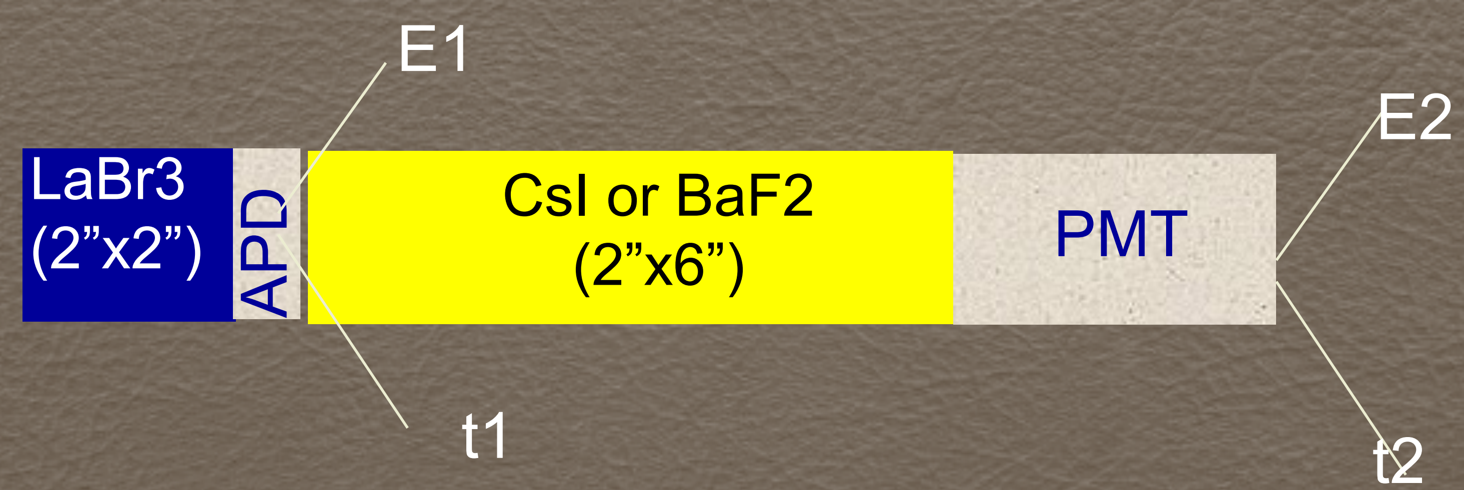
Decay of the resonances will be identified

4 POSSIBILITIES FOR A „GAMMA-TELESCOPE" ELEMENT

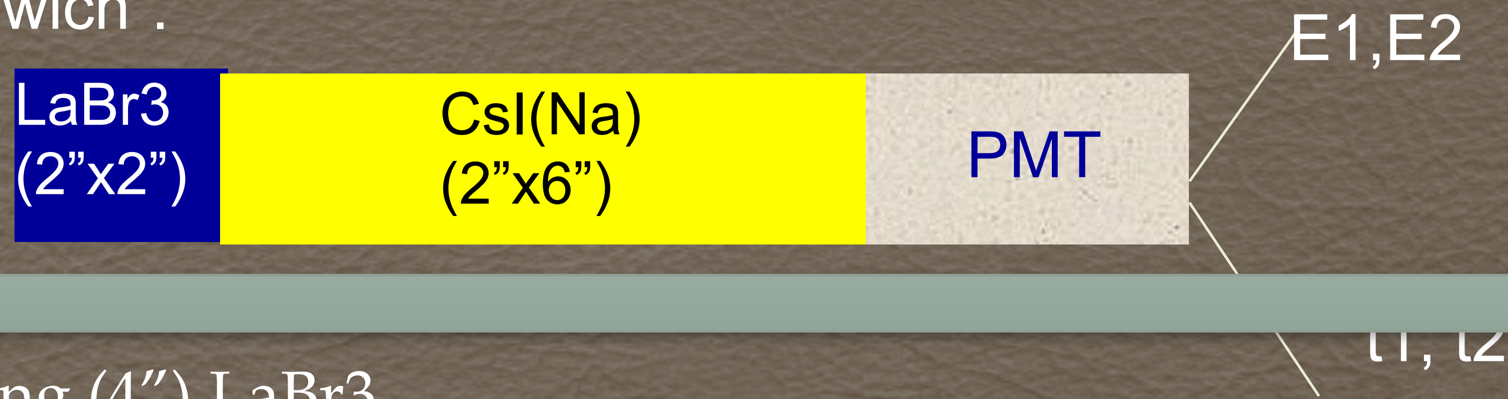
Possibility 1.



Possibility 2.

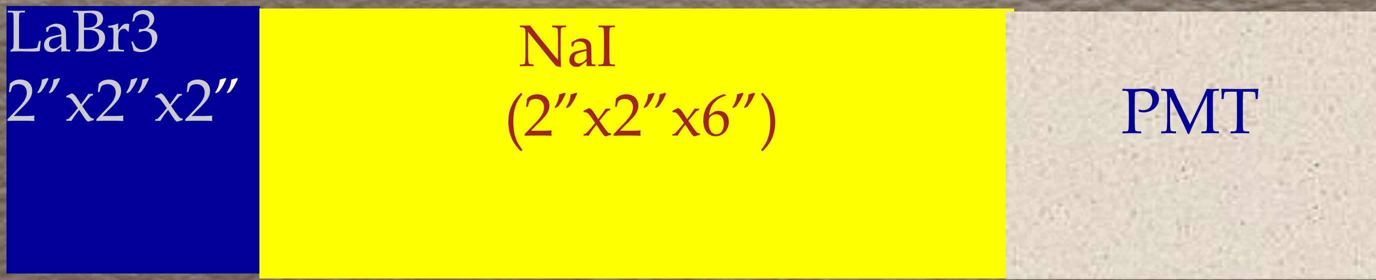


Possibility 3 – „phoswich".

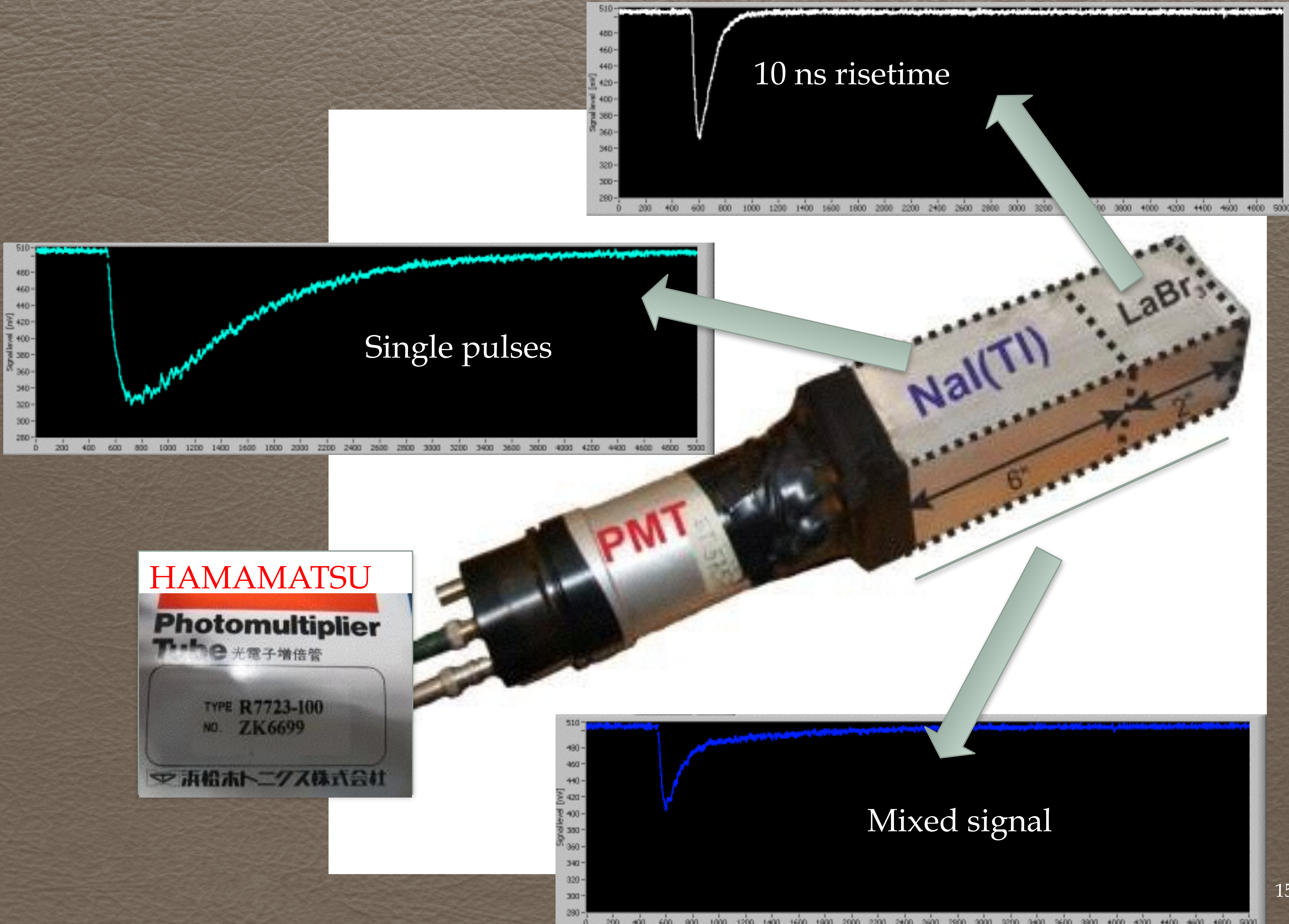


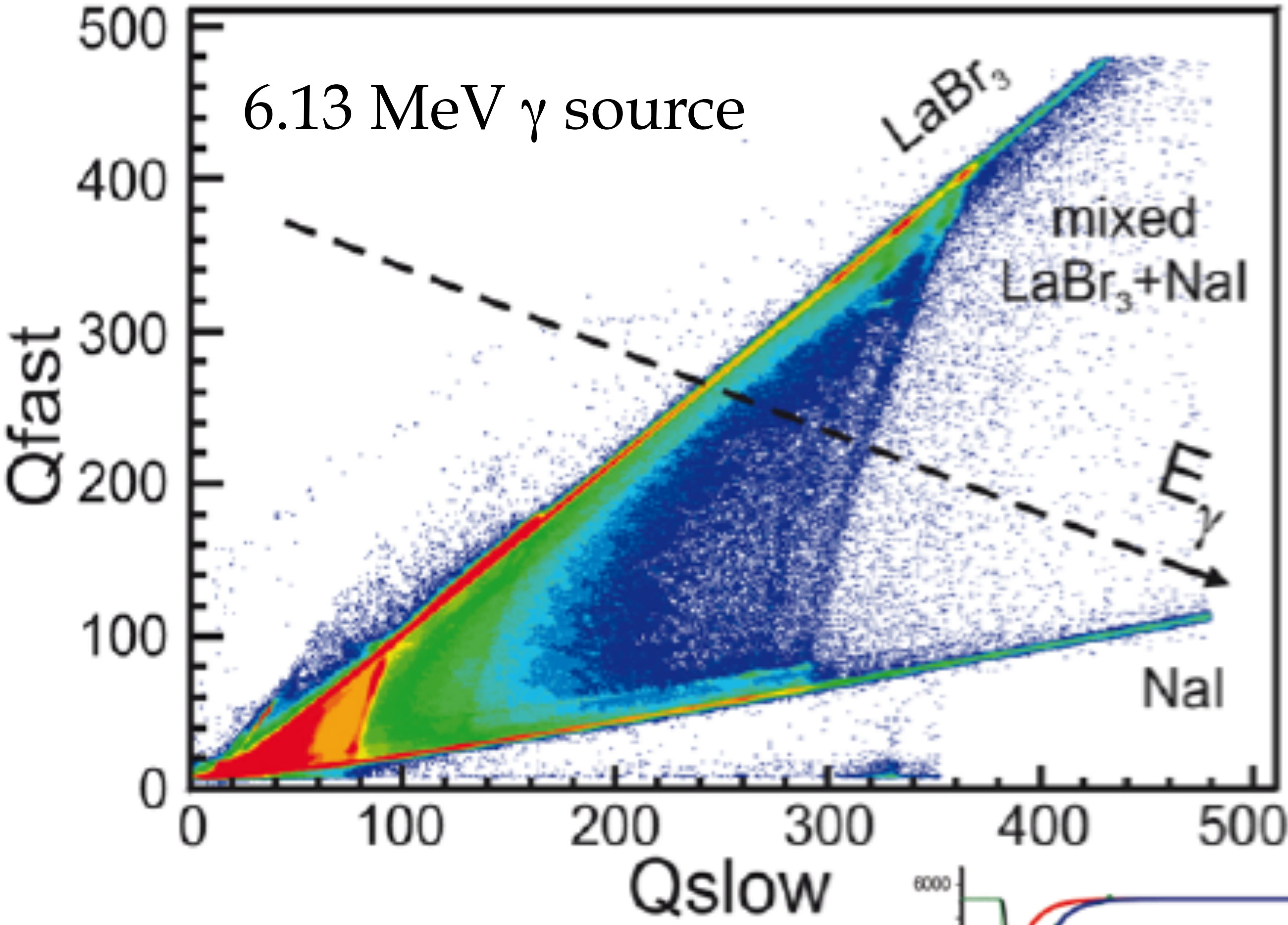
Possibility 4 – single long (4") LaBr3.

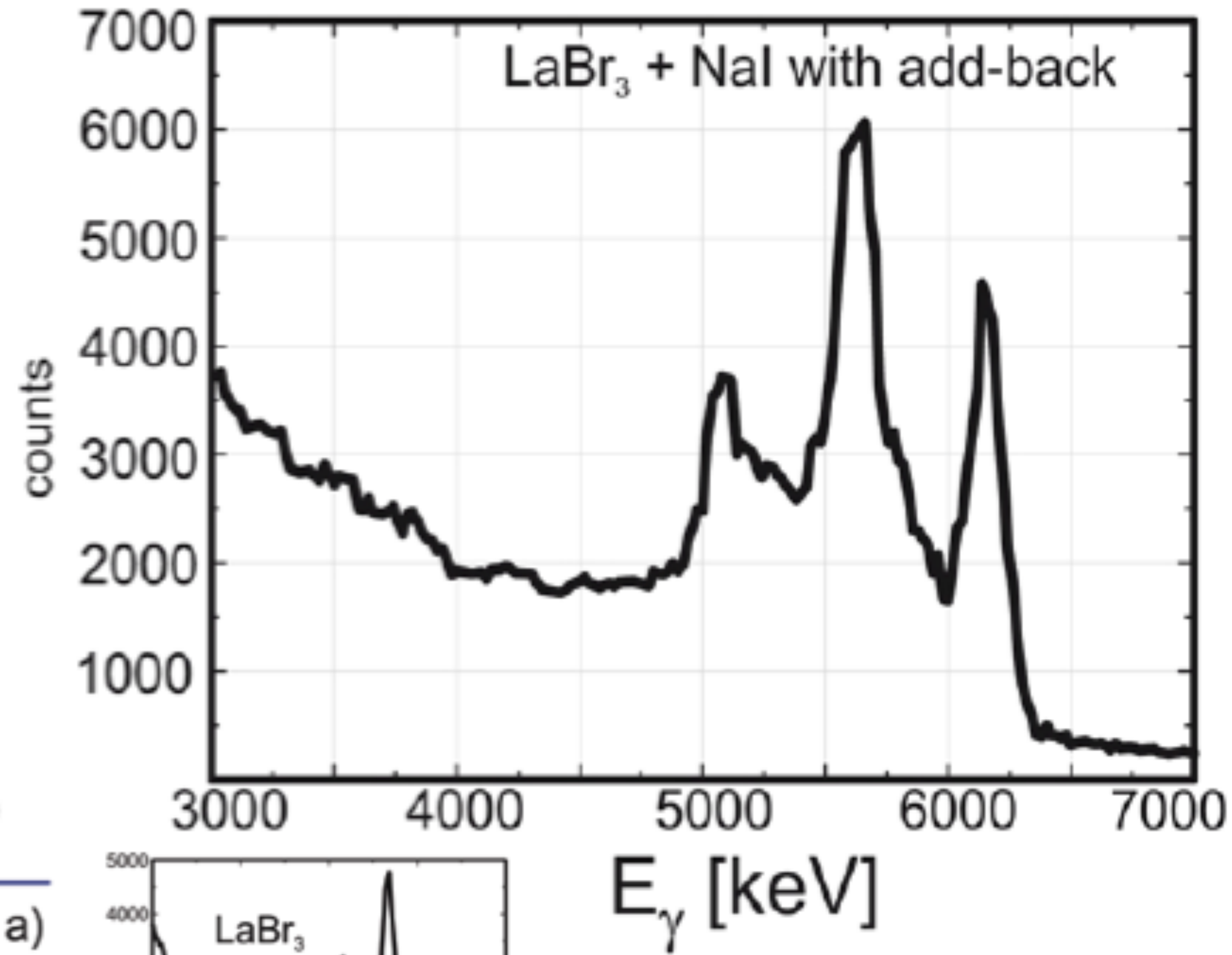
Basic element: a phoswich LaBr3+NaI

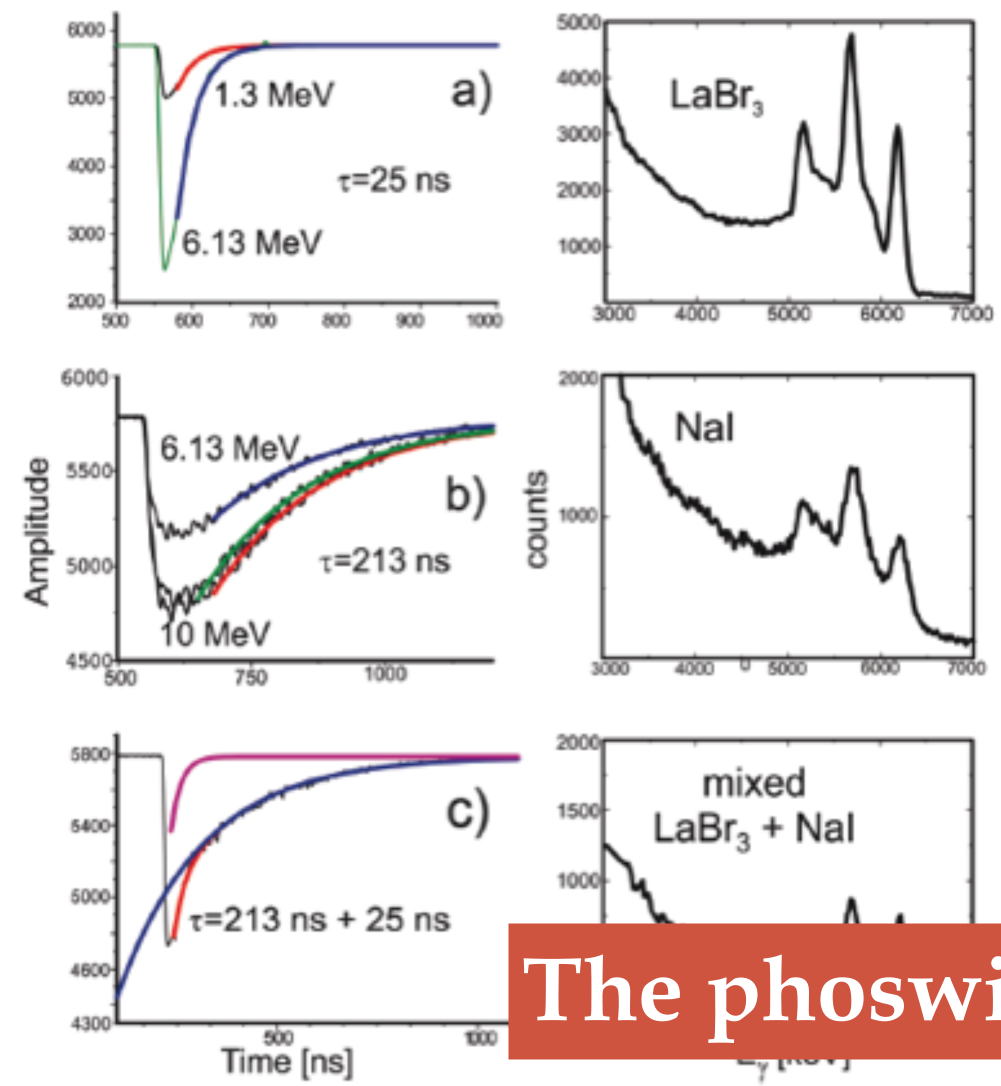


The PARIS PHOSWICH at work









A test measurement at IFJ PAN, Kraków (2011) with BafPro module from Milano

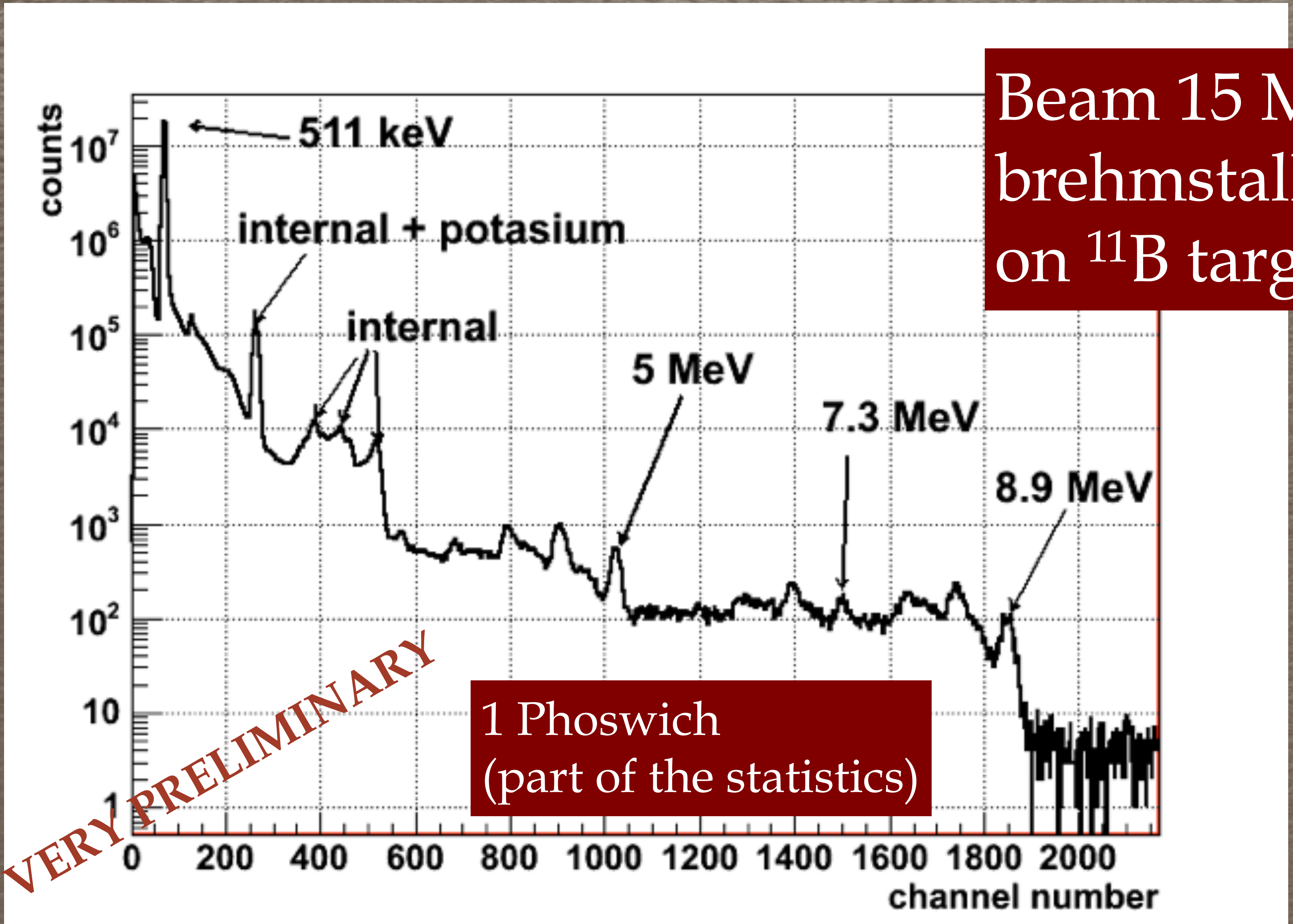
- Sources
- proton beam

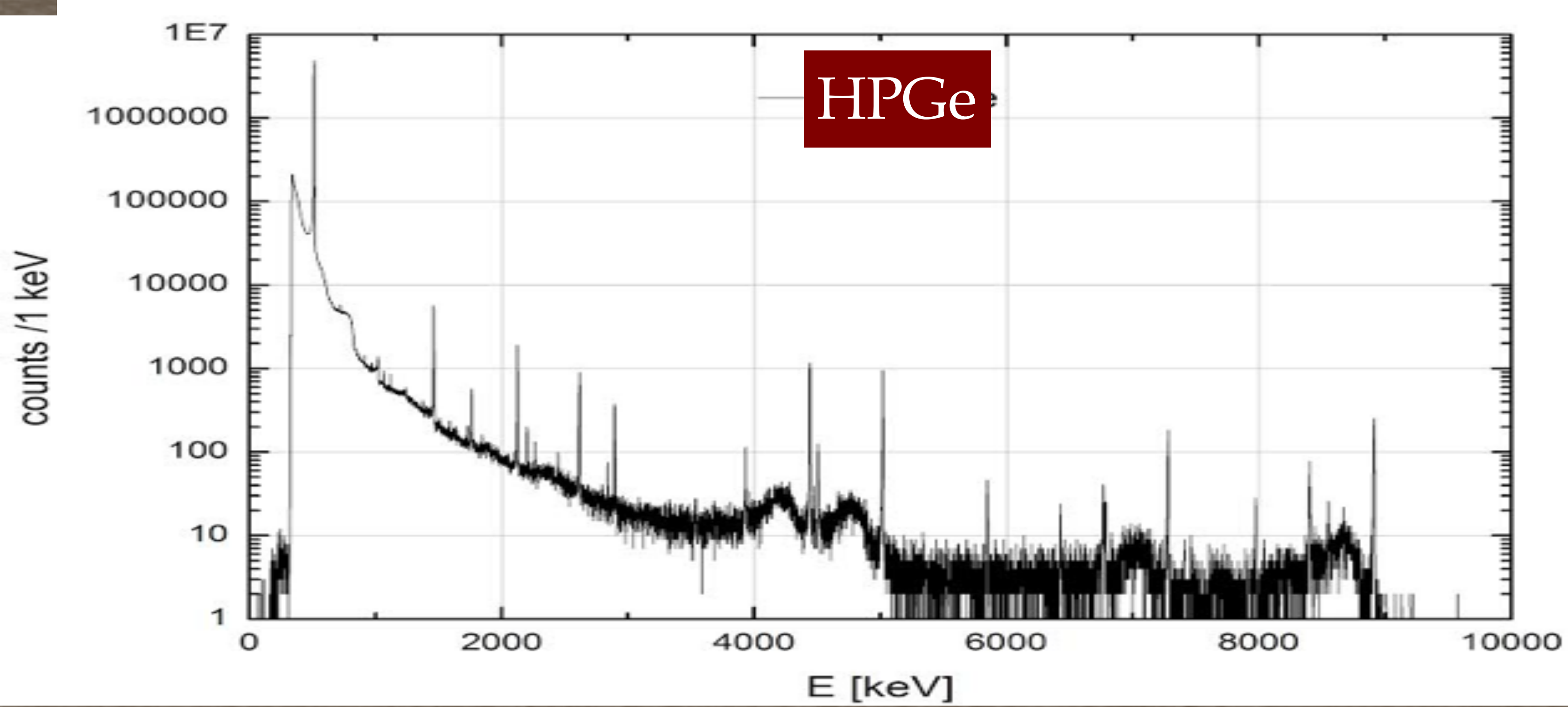
LaBr3 resolution (seen through 6″ long NaI): ca. 4%

M. Zieblinski et al., Acta Phys.Pol. B44, 651 (2013)

The phoswich concept works!

Beam 15 MeV electrons: brehmstallung gamma beam on ^{11}B target



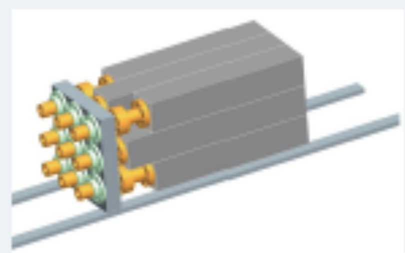
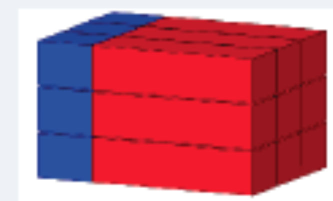
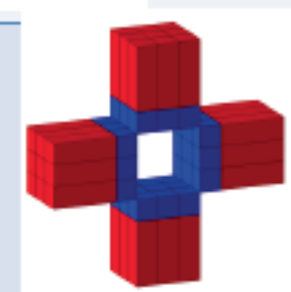
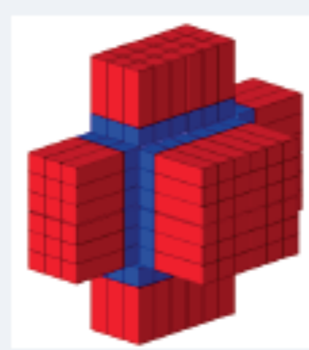
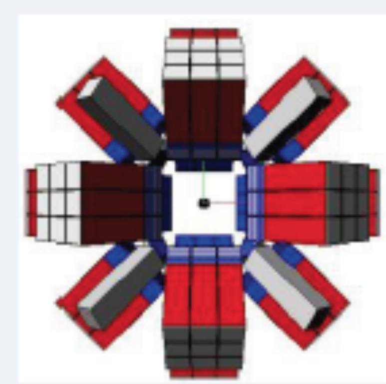
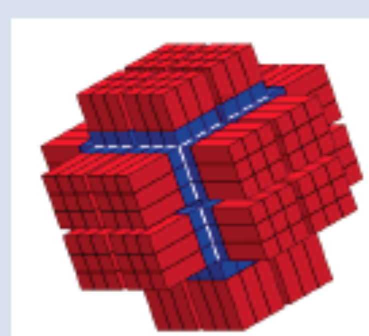


PARIS Demonstrator MoU

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

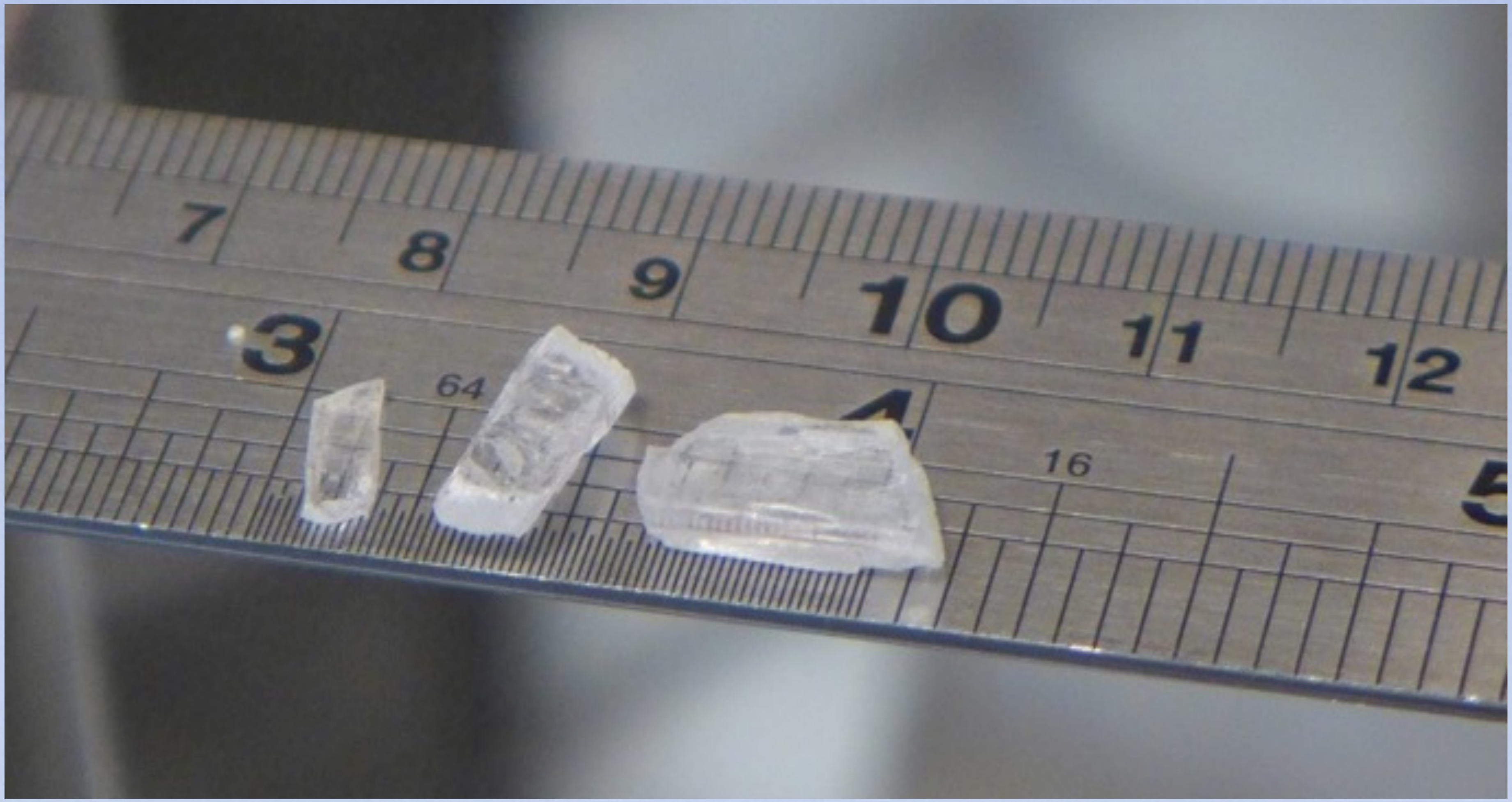
Since more than 3 partners already signed it (red), the MoU is effective.

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

Future for scintillators

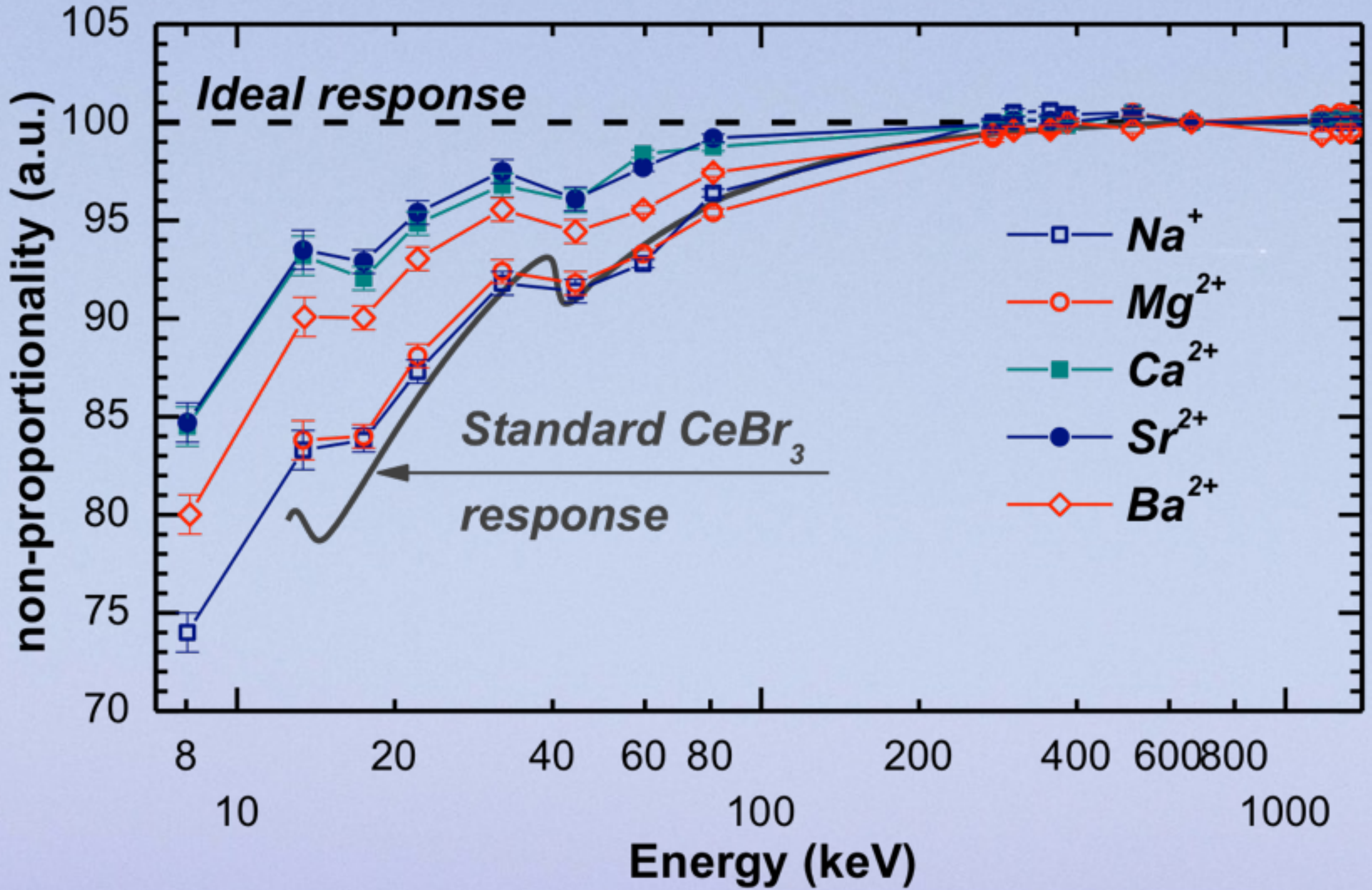
Current research on $CeBr_3$ co-doping



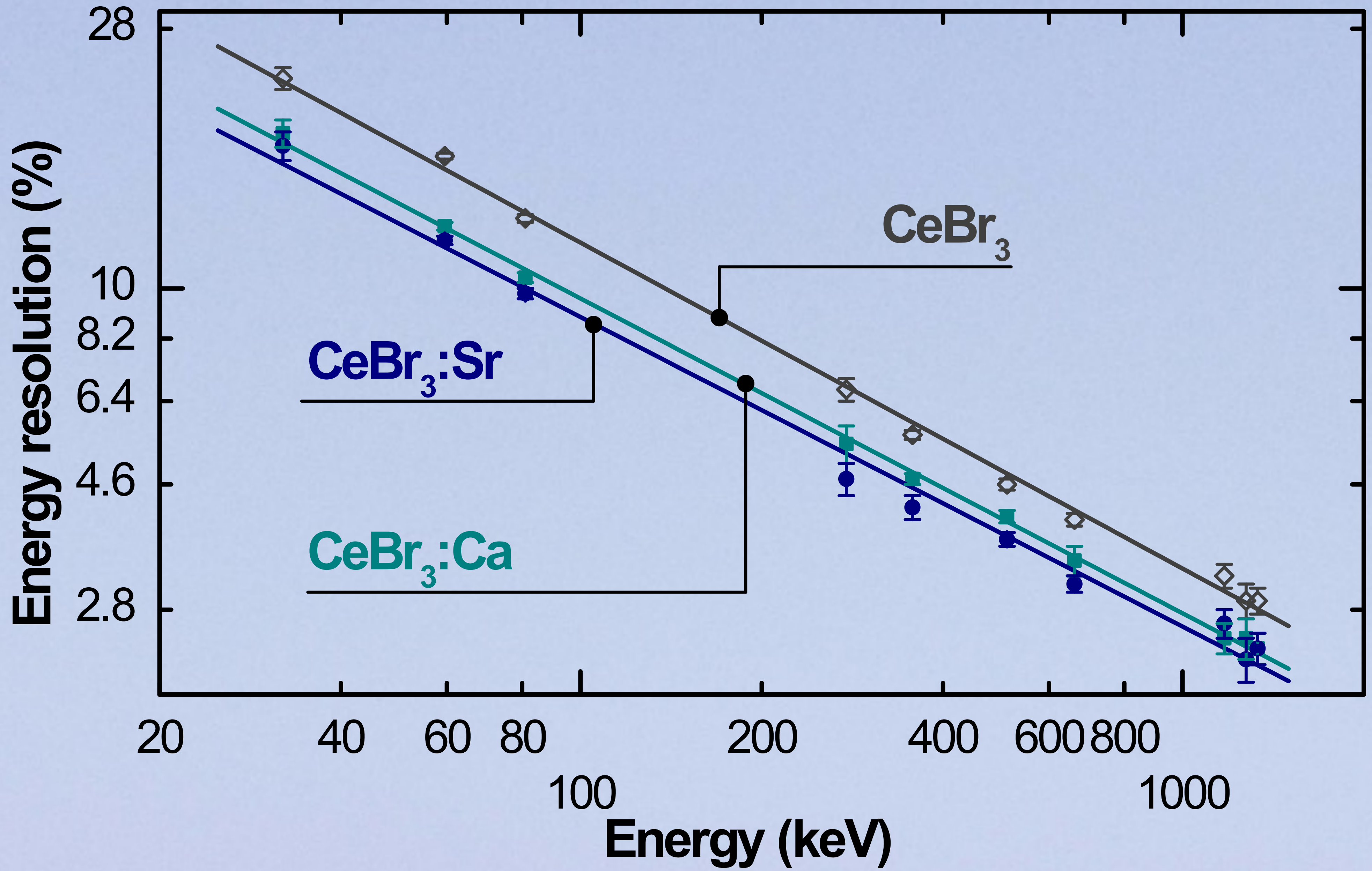
Scaling up of crystal size; up to ~ 1 cm^3 the proportionality improvement is now confirmed

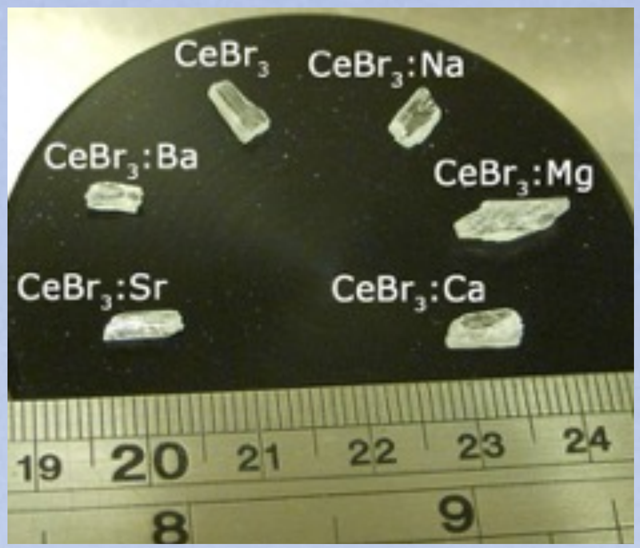
Observation and modeling of the co-doping effect on the scintillation mechanism

Aliovalent co-doping of $CeBr_3$ (and $LaBr_3$:Ce) improves the response proportionality



$CeBr_3$ energy resolution (as for $LaBr_3$:Ce) can be further enhanced by co-doping technique





Set of aliovalent co-doped $CeBr_3$ samples grown at the University of Bern by K. Krämer et al. and tested at the Delft University of Technology

Slides courtesy of F.G.A. Quarati

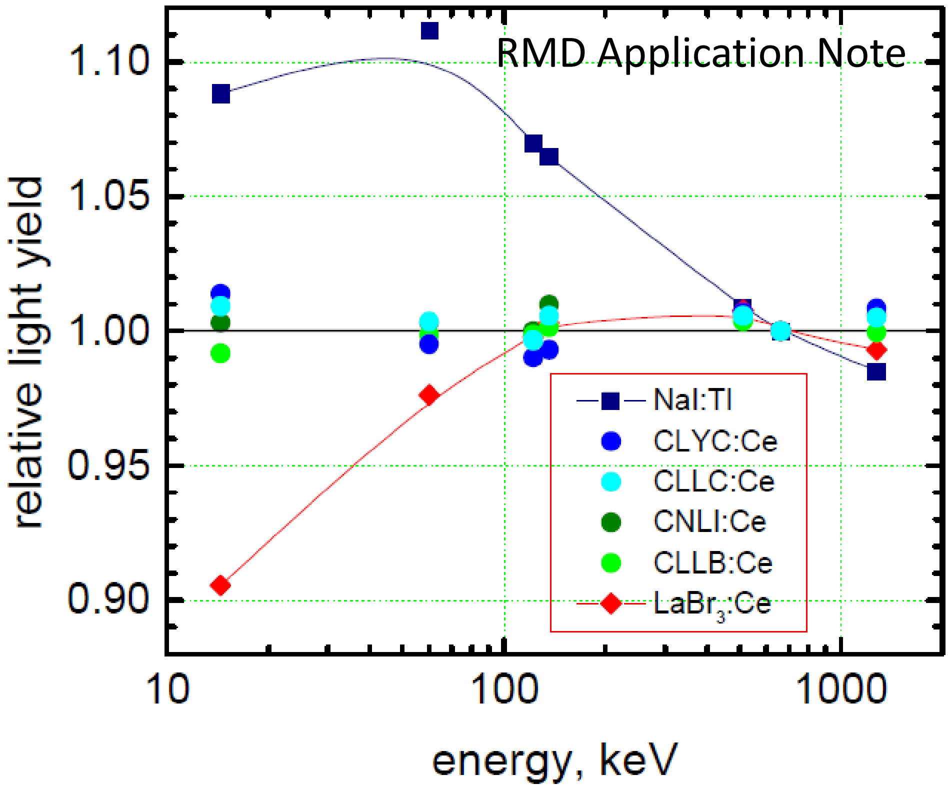
New materials

Elpasolite scintillators: CLYC, CLLC and CLLB

- The elpasolite crystals were discovered approximately 10 years ago.
- Excellent performances in terms of **gamma and neutron detection**.
- **CLYC:Ce (Cs_2LiYCl_6:Ce), CLLC:Ce ($Cs_2LiLaCl_6$:Ce) and CLLB:Ce ($Cs_2LiLaBr_6$:Ce)**

Gamma and Neutron detectors:

- High **energy and time resolution**
- Neutron-gamma **pulse shape discrimination** capability
- High **linearity**
- High **efficiency** for gamma and neutrons
- High **light yield**

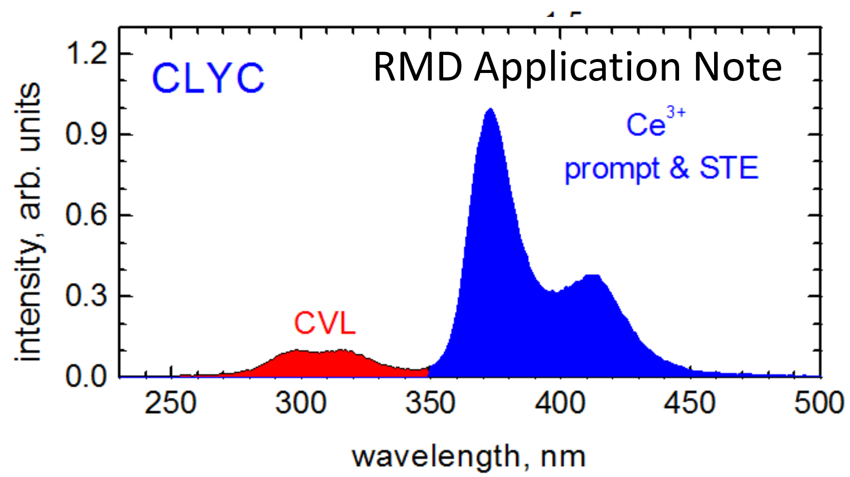


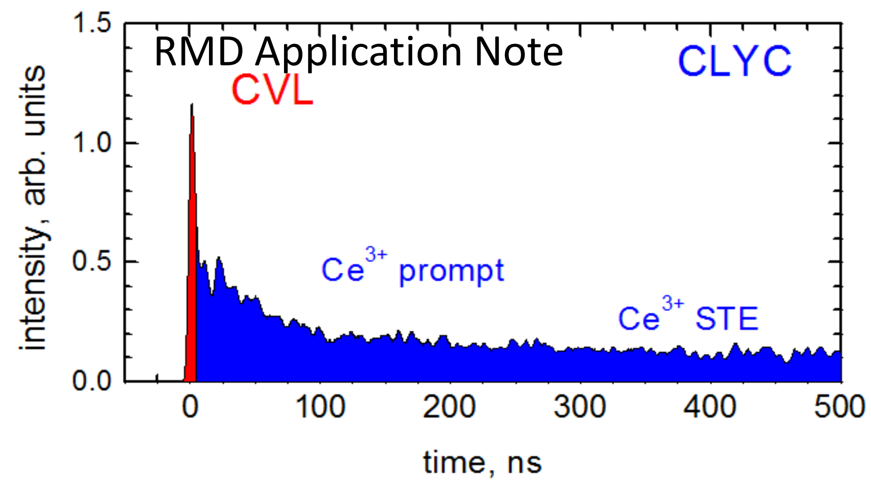
	CLYC	CLLC	CLLB
Density [g/cm^2]	3.3	3.5	4.2
Emission [nm]	290 CVL 390 Ce$^+$	290 CVL 400 Ce$^+$	410 Ce$^+$
Decay Time [ns]	1 CVL 50,~1000	1 CVL 60, ≤ 400	55, ≤ 270
Light yield [ph/MeV]	20000	35000	60000
Light yield [n/MeV]	70000	110000	18000
En. Res. at 662 keV [%]	4	3.4	2.9
PSD	Excellent	Excellent	Possible

RMD Application Note

Gamma and neutron identification

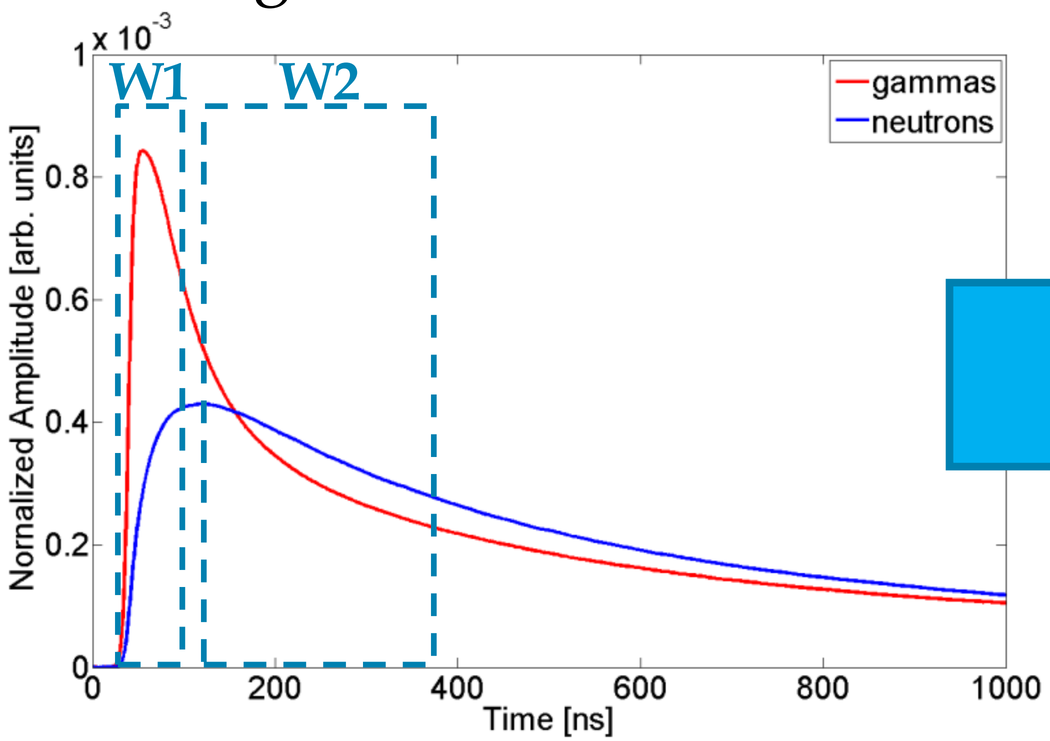
The different scintillation light decay response (CVL and Ce^{3+}). The gamma-ray signal contains the CVL component, instead neutron signal does not contain CVL.

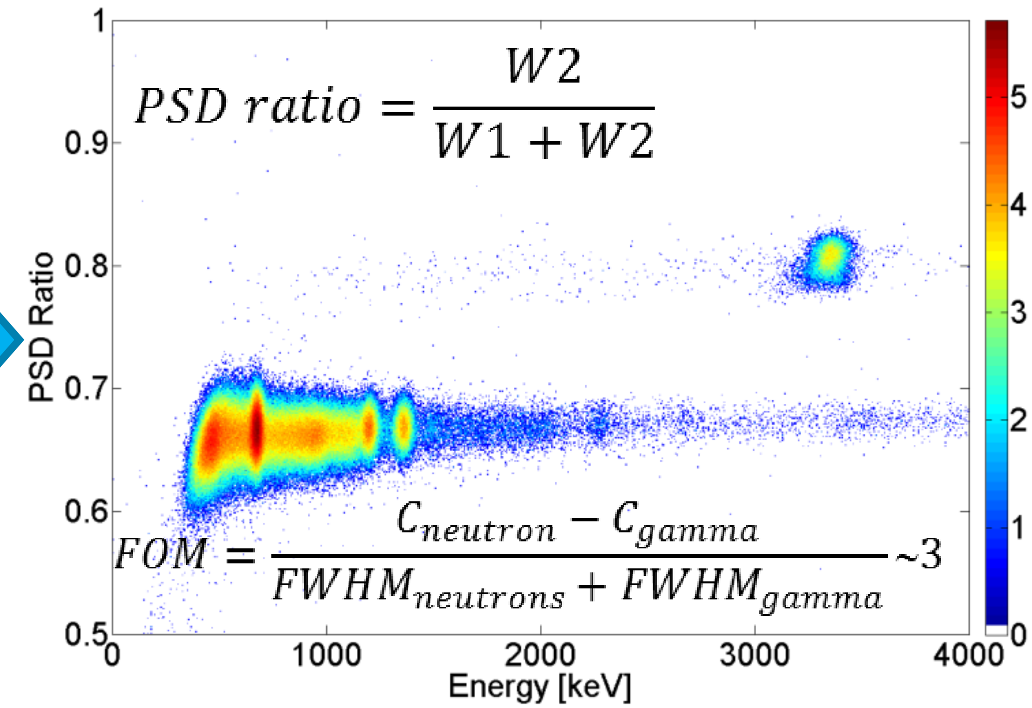




PSD (pulse shape discrimination) is based on the **differences in the scintillation decay response** to gamma and neutrons.

Width:
W1=60ns
W2=250ns
Range:
W1=0ns-60ns
W2=110ns-360ns





Neutron identification

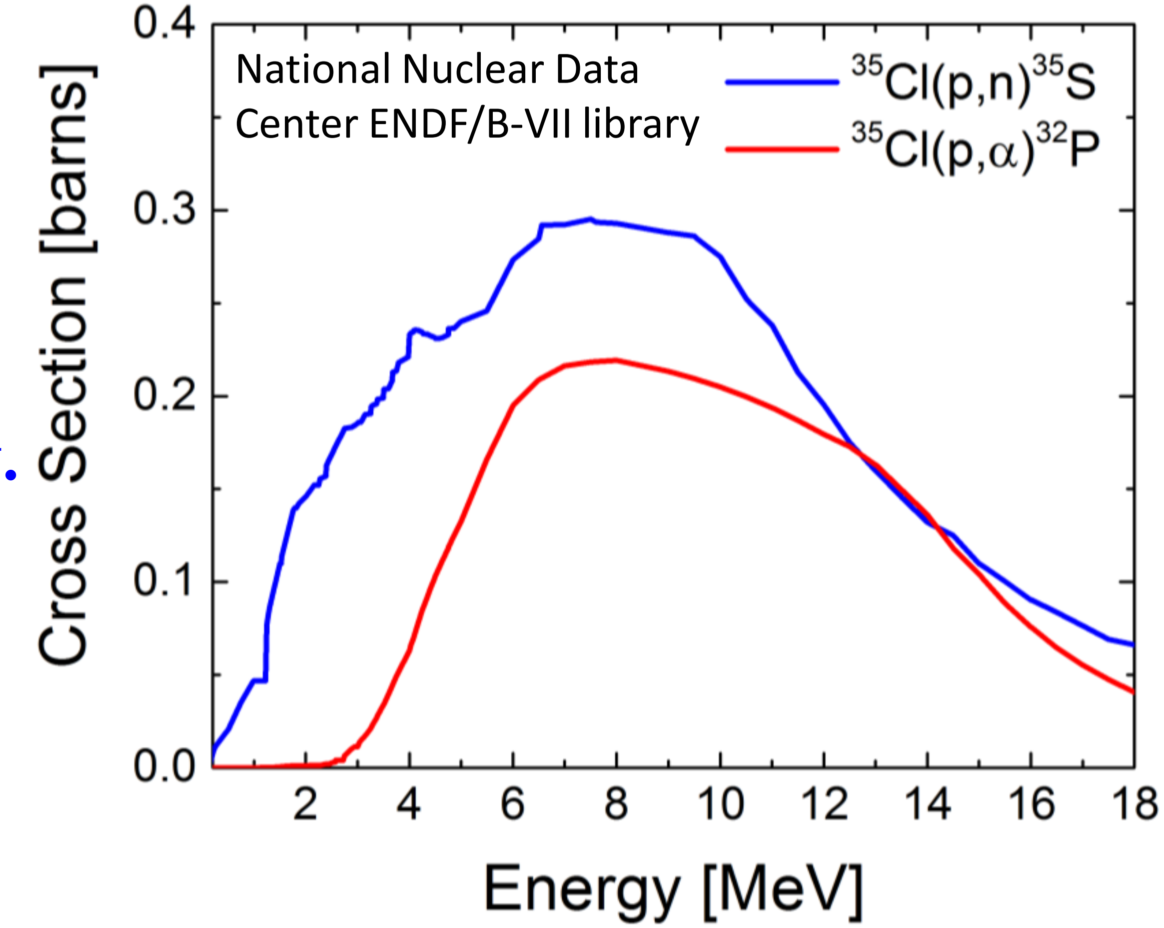
CLYC scintillators can detect both thermal and fast neutrons.

Fast neutron detection

The kinetic energy of the neutron can be measured:

- Via the time signal using **Time of Flight** (FWHM < 1 ns)
- Via the **energy signal**

CLYC:Ce is the only detector with this capability.



Fast neutrons are detected using the reaction **$^{35}Cl\ (n, p)^{35}S$ and $^{35}Cl\ (n, \alpha)^{32}P$.**

Neutron spectrometer: proton or alpha energy is linearly related to neutron energy.

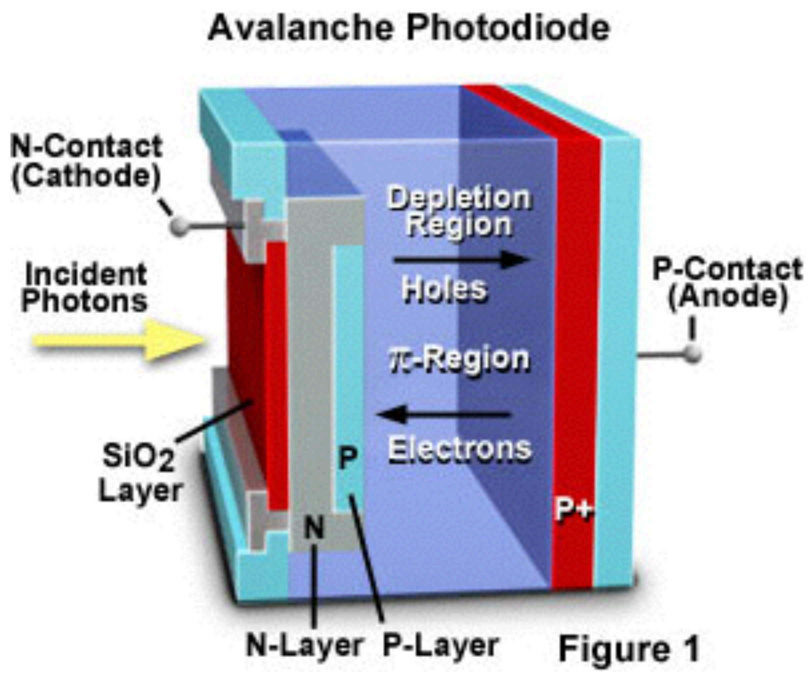
1 CLYC:Ce sample enriched with **^{7}Li** to emphasize the fast neutron detection

^{7}Li enriched CLYC:Ce has less sensitivity to thermal neutrons (less background between 3.0-3.5 MeV).

^{7}Li enriched CLYC:Ce has an excellent sensitivity to fast neutrons.

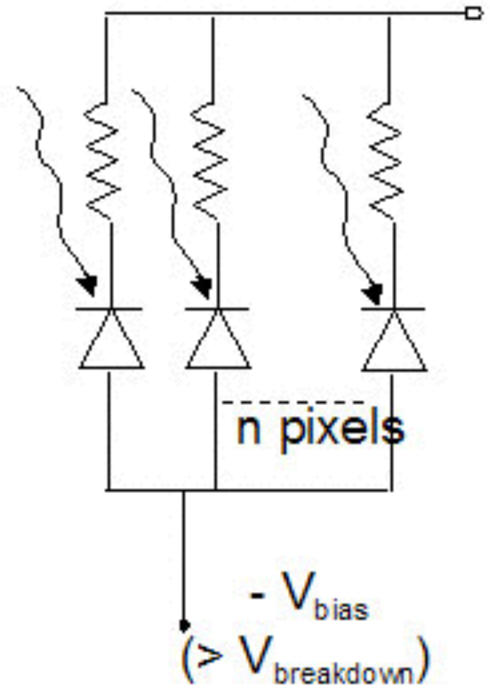
Is the PMT dead?

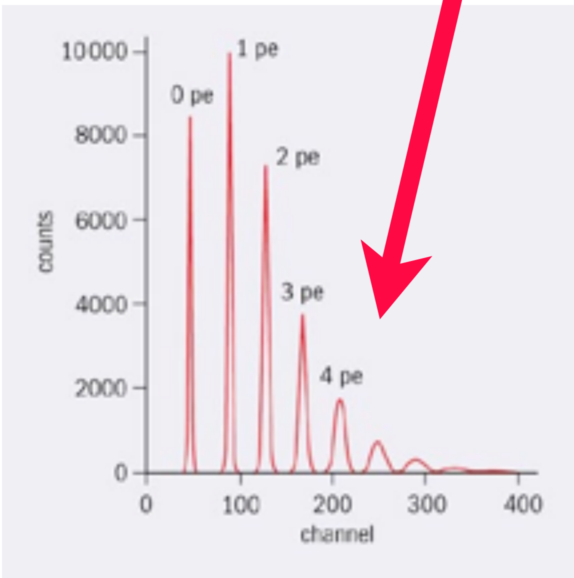
APDs and silicon photomultipliers



SiPM:

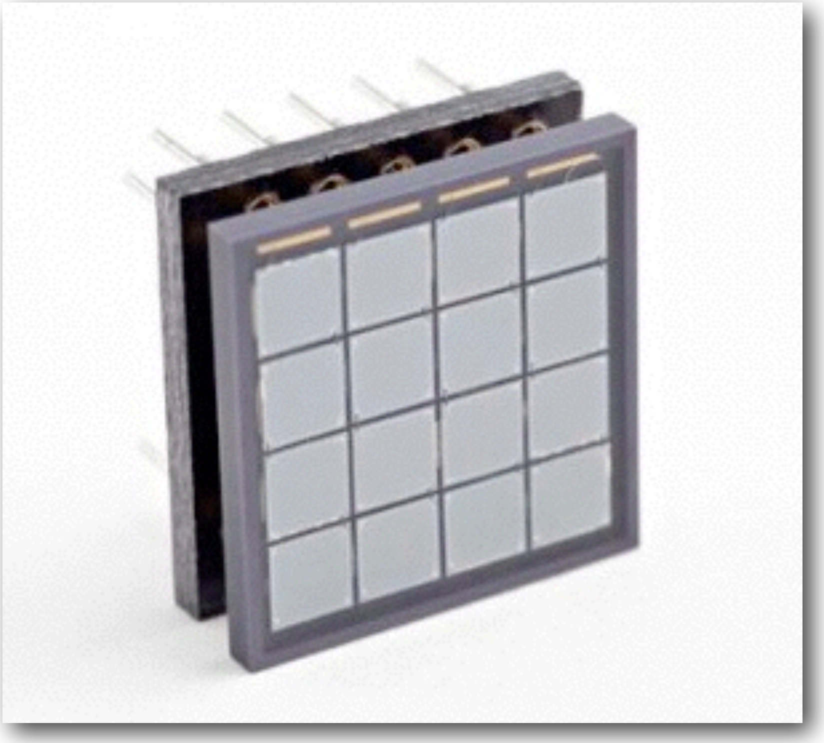
- matrix of n pixels (~1000) in parallel
- each pixel: GM-APD + $R_{quenching}$

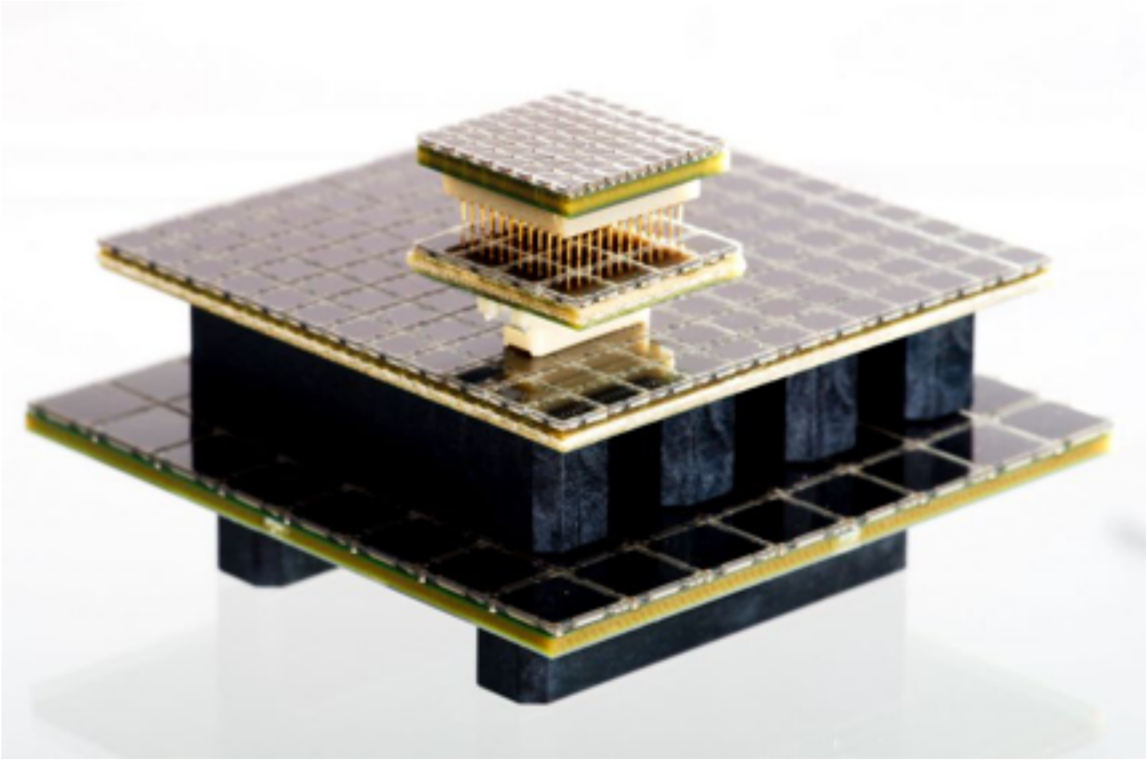




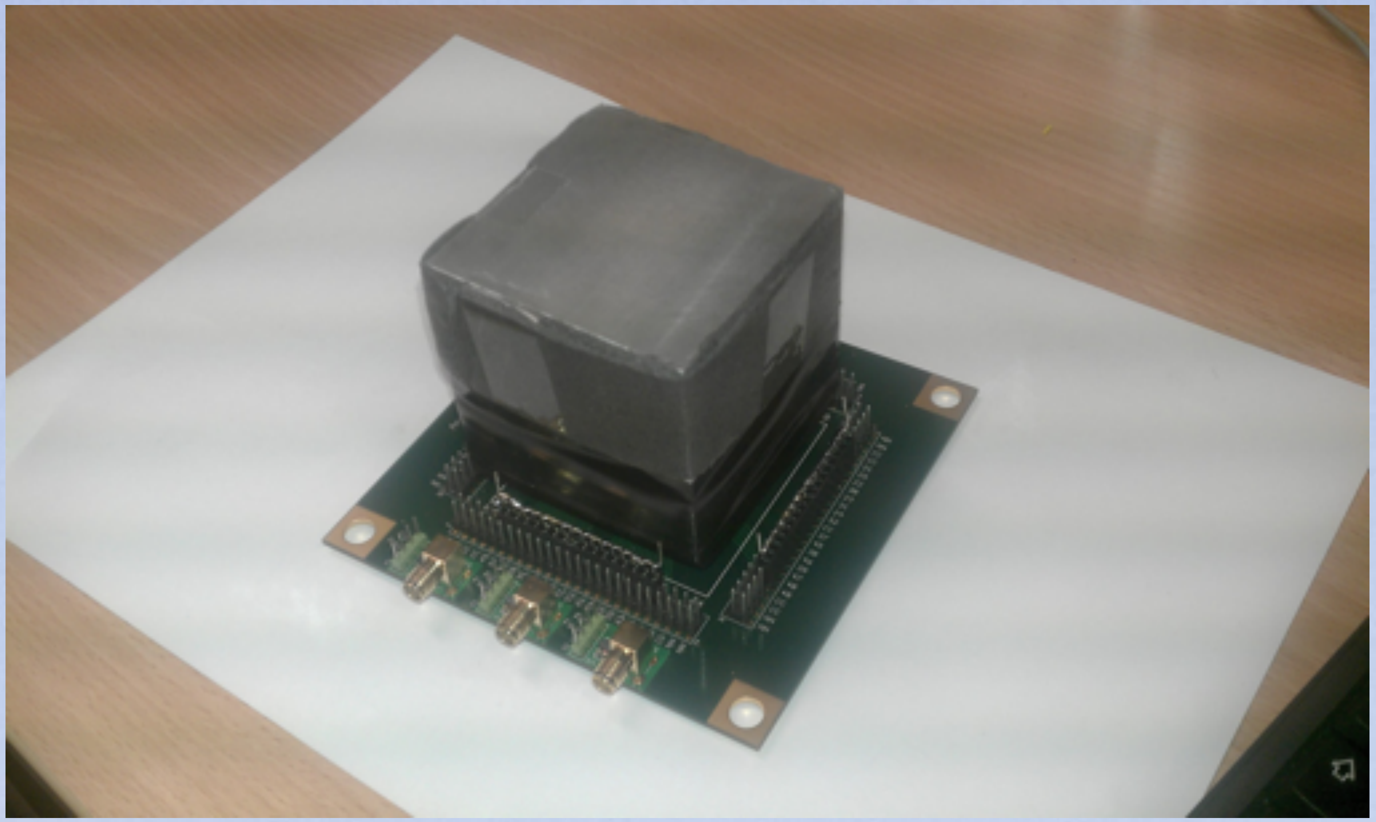
Silicon Photomultipliers

- Developments of large arrays of SiPMs
- Insensitive to magnetic fields
- Bespoke electronics and readout developed
- Suffer from high dark current GREATLY IMPROVED
- Major gain instability with temperature GREATLY IMPROVED
- Excellent timing resolution (100s of ps)

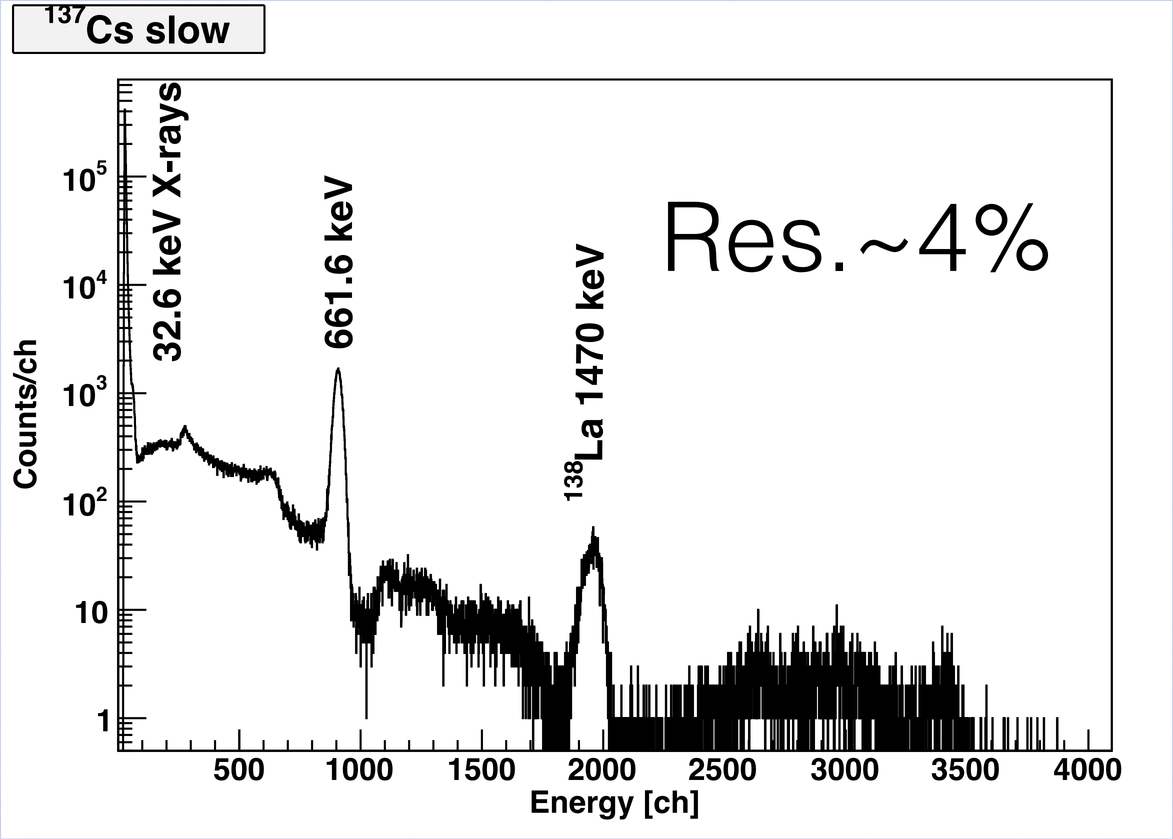




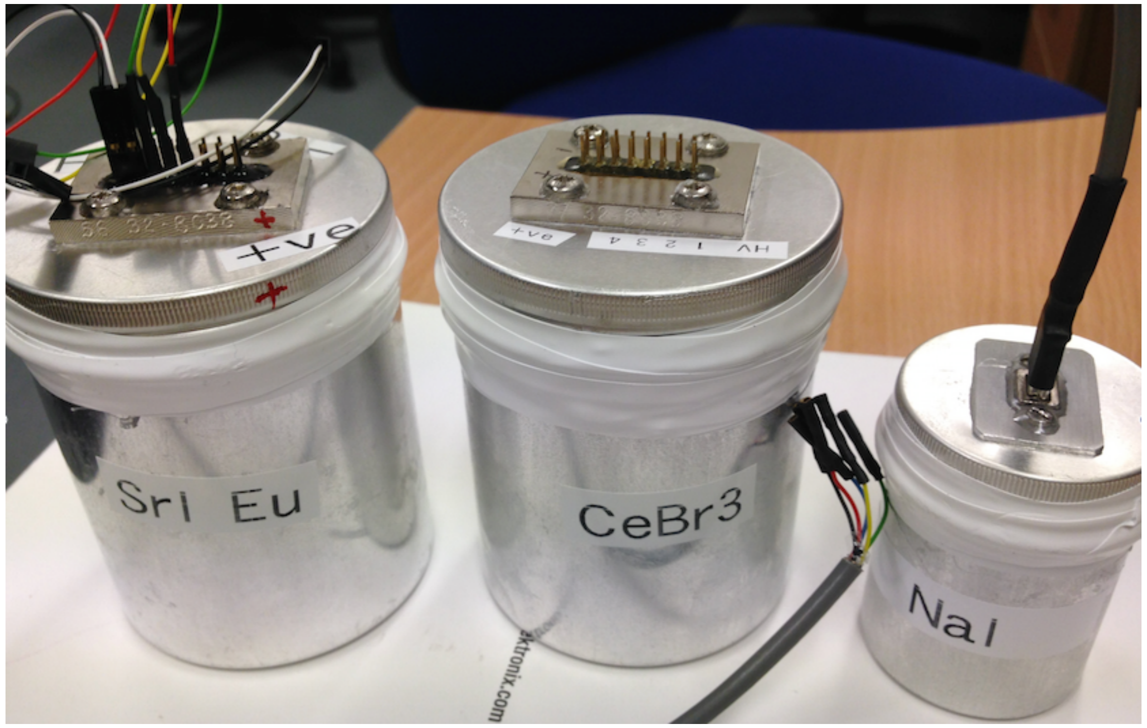
2” LaBr3 + “chessboard” SiPM array

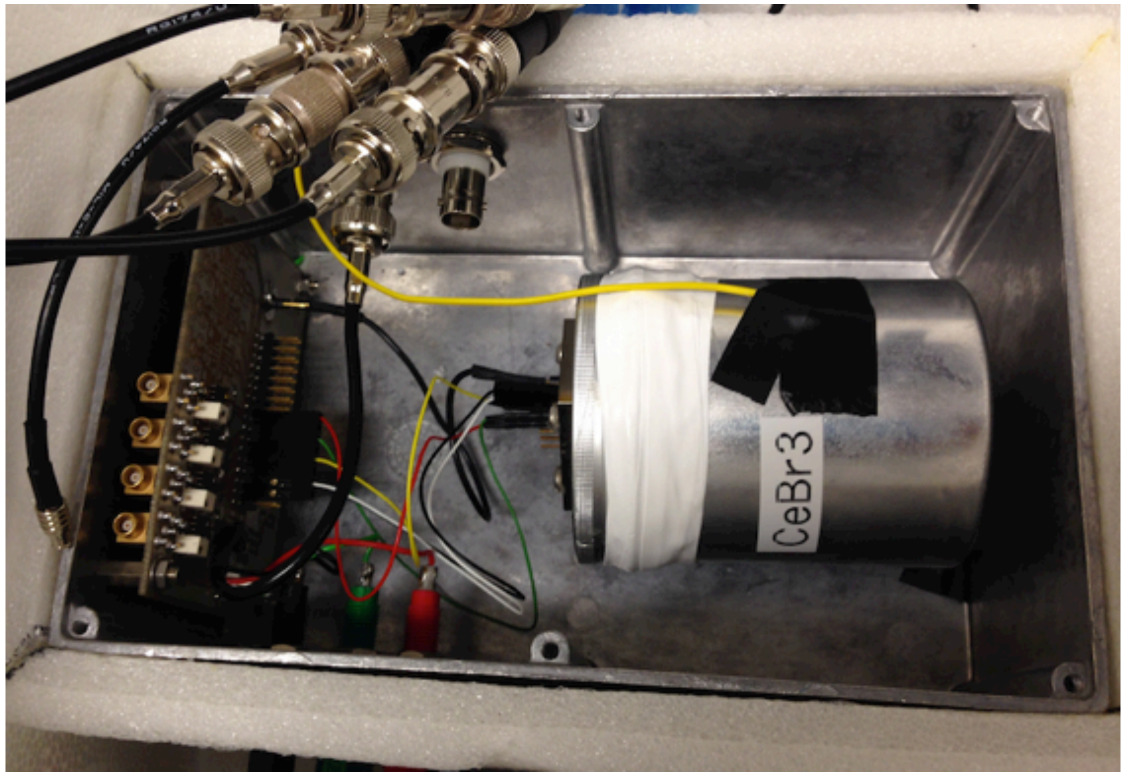


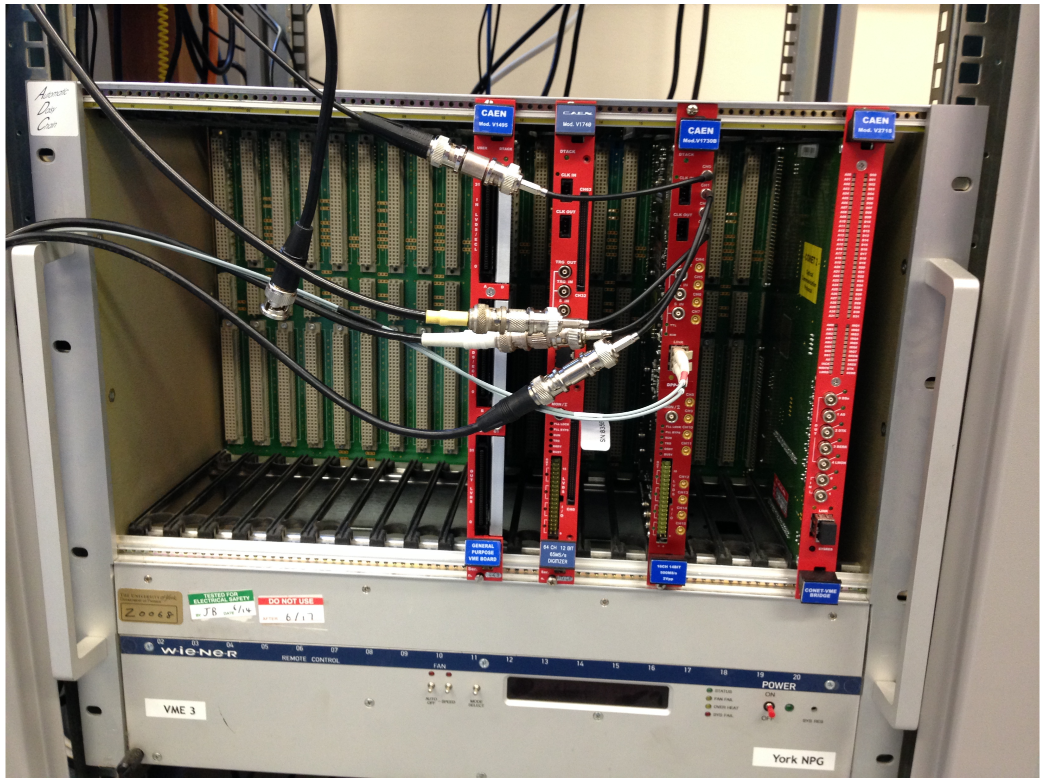
8 x 8 array of SensL C-Series SiPMs



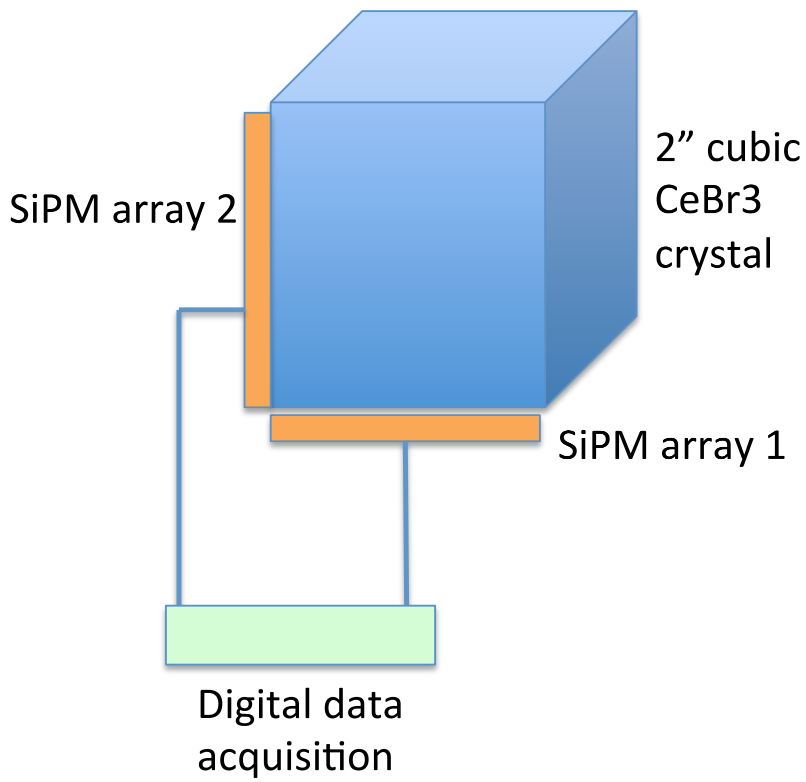
Specialist glove box at York allows us to can hygroscopic crystals or couple SiPMs to bare crystals

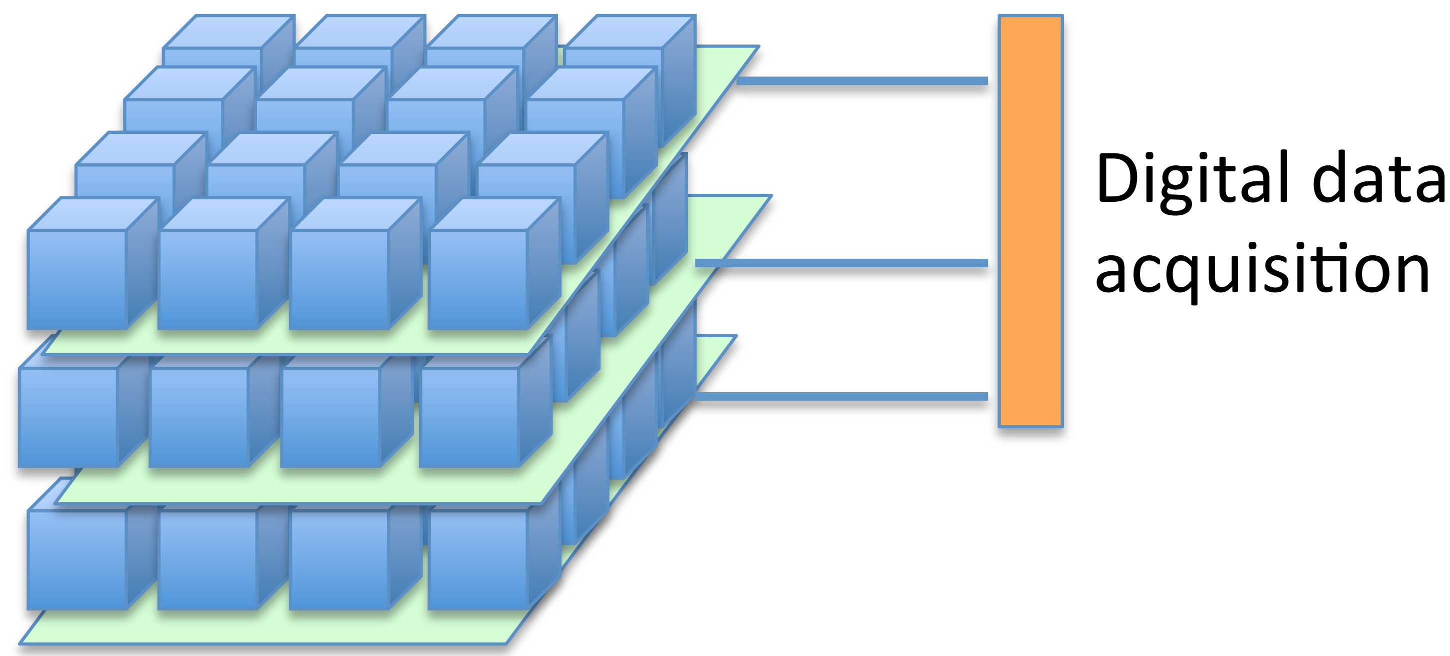




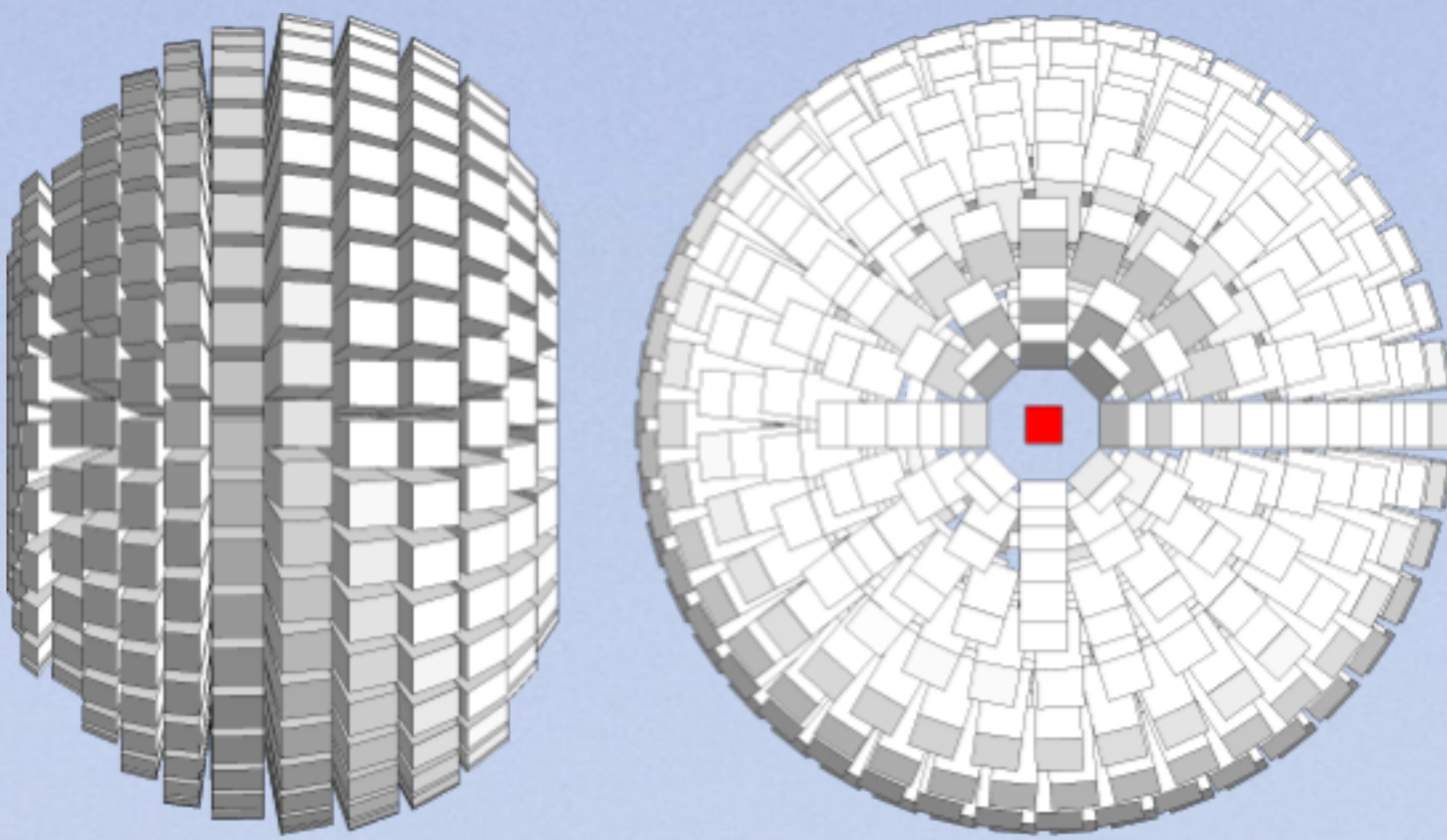


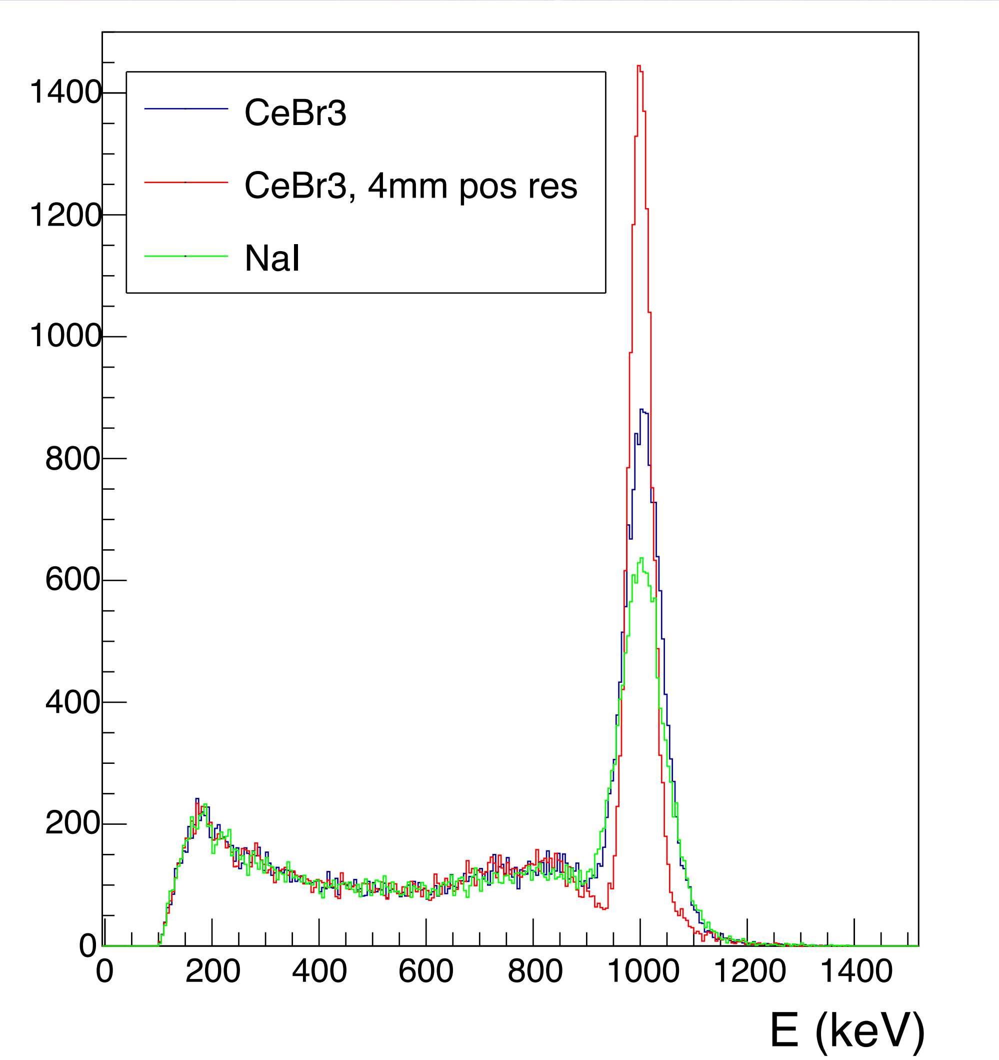
Ways to rethink the scintillator paradigm?





Ideal for future scintillator arrays at high energy facilities?





Finis