PARIS : Detectors status and beyond

Olivier Dorvaux, IPHC/University of Strasbourg
for the PARIS collaboration

PARIS (*P*hoton *A*rray for studies with *R*adioactive *I*ons and *S*table beams) is devoted to studies on both nuclear structure and reaction dynamics (exotic collective phenomena including giant resonances and rapid shape transitions, discrete gamma, ...).
To contend with the variety of physics cases (16 @ SPIRAL2), the PARIS array needs to be:

- **as efficient as possible in a wide energy range (from 50 keV to 40 MeV),**
- **with the best possible energy resolution for low energy gamma rays (~4% @ 662 keV),**
- **with a sub-nanosecond time resolution to discriminate gamma-rays against neutrons, (i.e. ~500 ps @ 511 keV**
- **with a high granularity (gamma-ray multiplicity, gamma-ray coincidence, Doppler correction),**
- **able to accept a high counting rate (50 kHz)**
- **modular and position sensitive**
- **transportable (experiments @ different facilities : GANIL/SPIRAL2, IPNO, HIL Warsaw, CCB Krakow, SPES/LNL, HIE-ISOLDE, TIFR Mumbai,…)**
- **as cheap as possible**

Overview

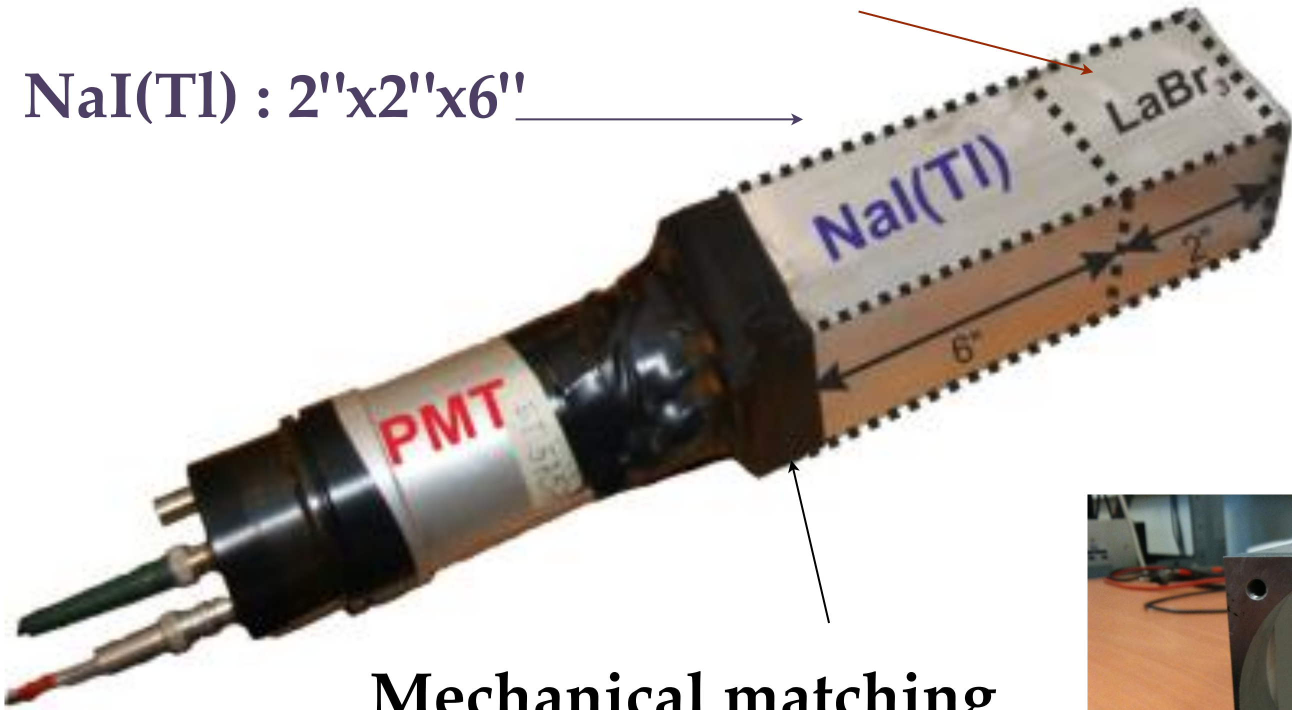
- General presentation of PARIS detector and its characteristics
- few words on simulation/shielding working close to an electromagnetic field
- PARIS as a neutron detector ?
- Conclusion

the PARIS design

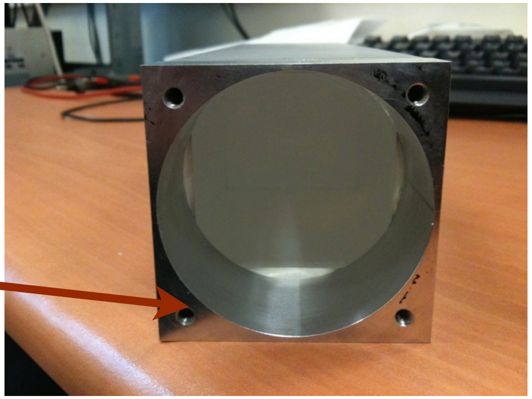
Choice is based on a « Phoswich » solution manufactured by Saint-Gobain Crystals encapsulated in 0,5 or 1 mm Al cap (+coating 0,3mm) and composed by two shells :

LaBr3(Ce) or CeBr3 : 2''x2''x2''

NaI(Tl) : 2''x2''x6''

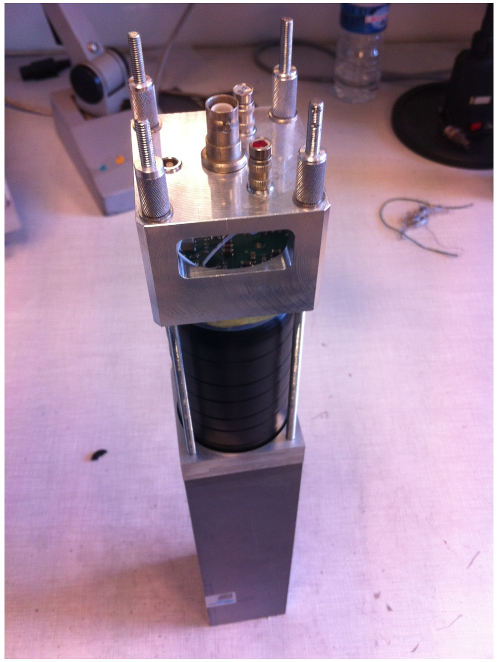


Mechanical matching and PM tube fixing



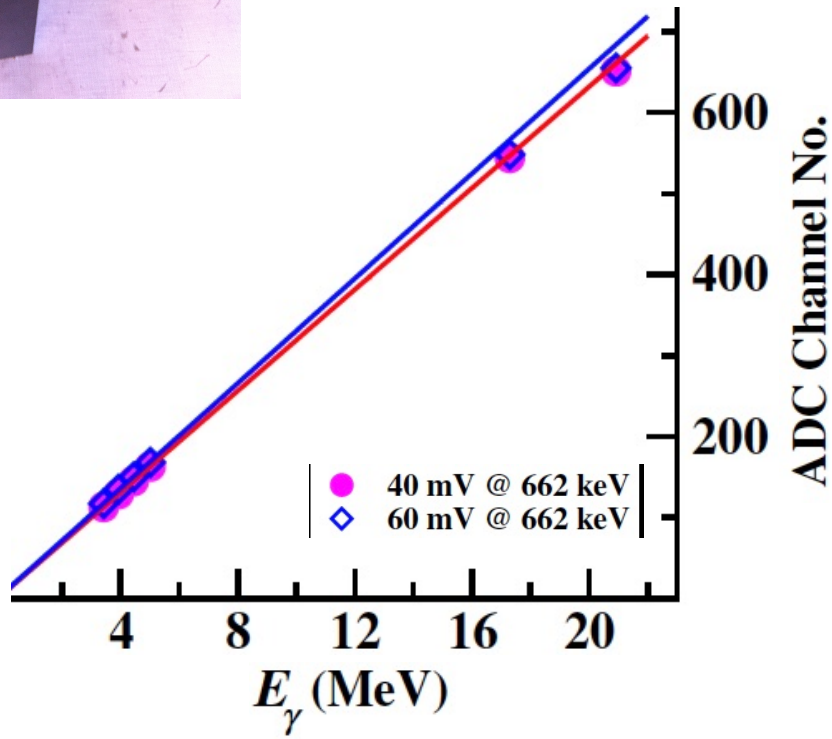
the PM tube

- Coupling with a R7723-100 Hamamatsu PM tube (high QE, good linearity, low gain, …) fixation with rods for a better stability
- Home made IPHC Voltage divider
  - design based on the Hamamatsu one (E5859-15MOD D Type Socket)
  - new PCB
  - Anode and 2 dynodes (between 6,7 and 8) outputs



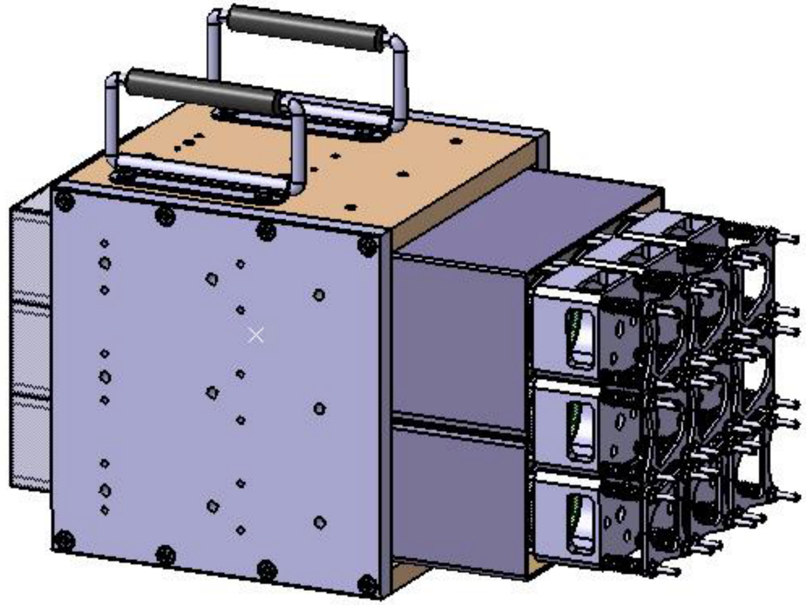
- and has shown a remarkable linearity up to 22 MeV γ-rays

(see C. Ghosh et al., JINST 11 P05023 (2016))

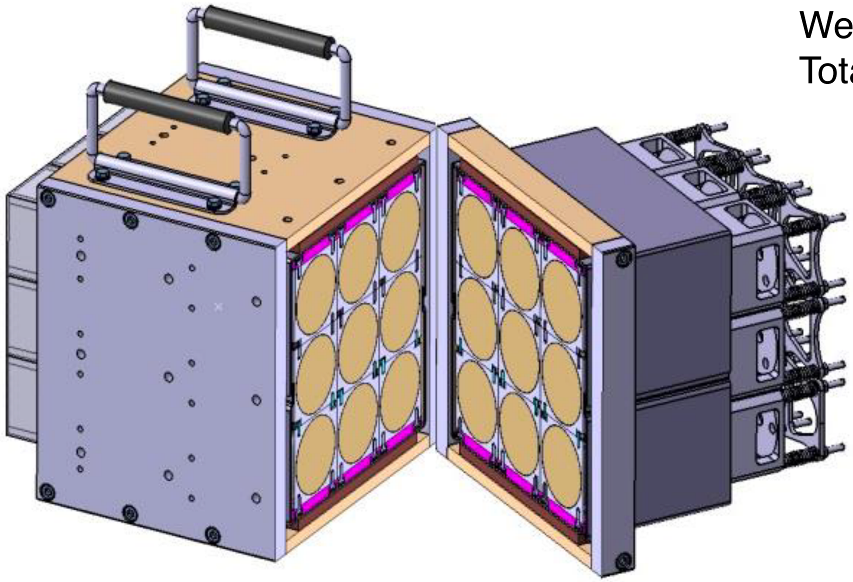


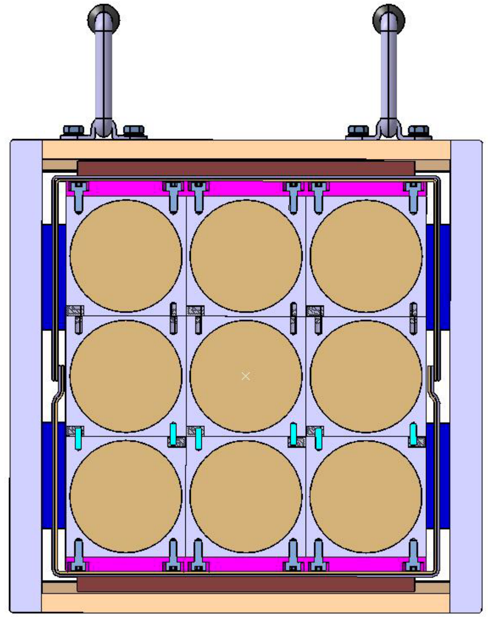
the mechanical design

- **Special mechanical design to ensure the optical coupling and compatible with the assembly in a "cluster" configuration of 9 phoswiches**



Weight 9 cristal LaBr3+NaI ~ 23 kg
Weight cluster ~ 11 kg
Total ~ 34 kg

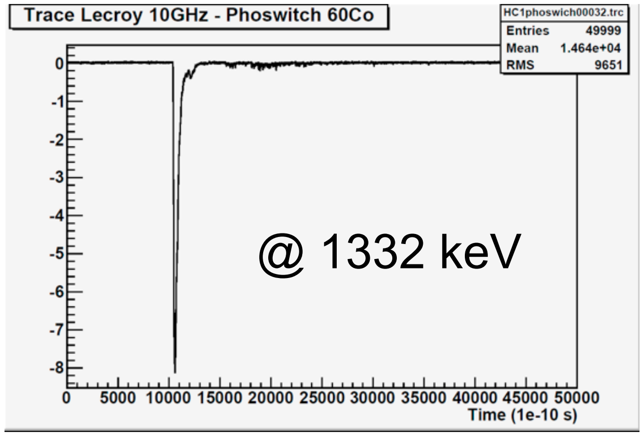




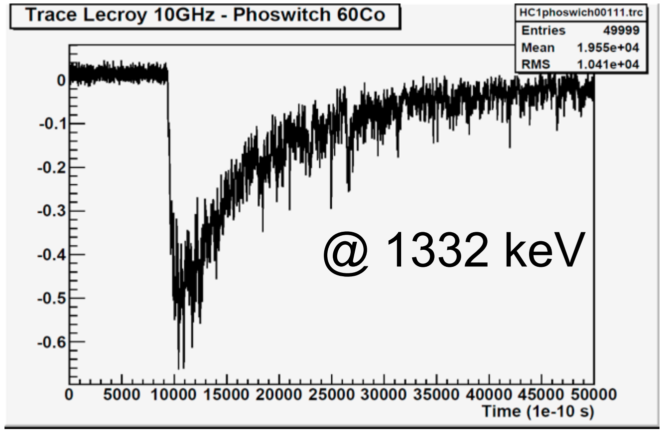
Courtesy of G. Minier, IPN Orsay

the Paris performances : 2 crystals - 1 output signal

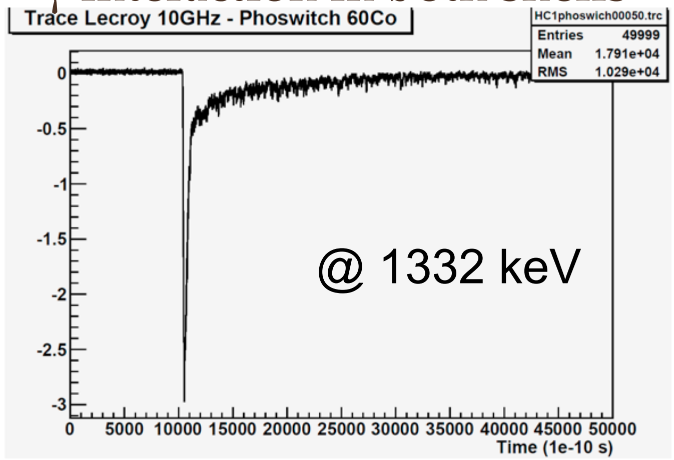
γ interaction in $LaBr_3$ only

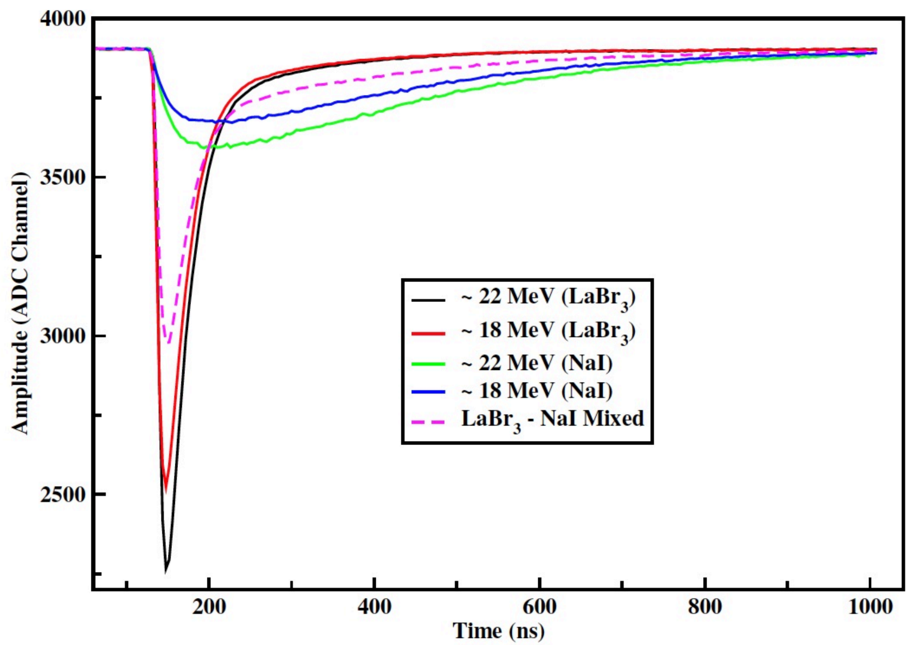


γ interaction in NaI only



γ interaction in both shells

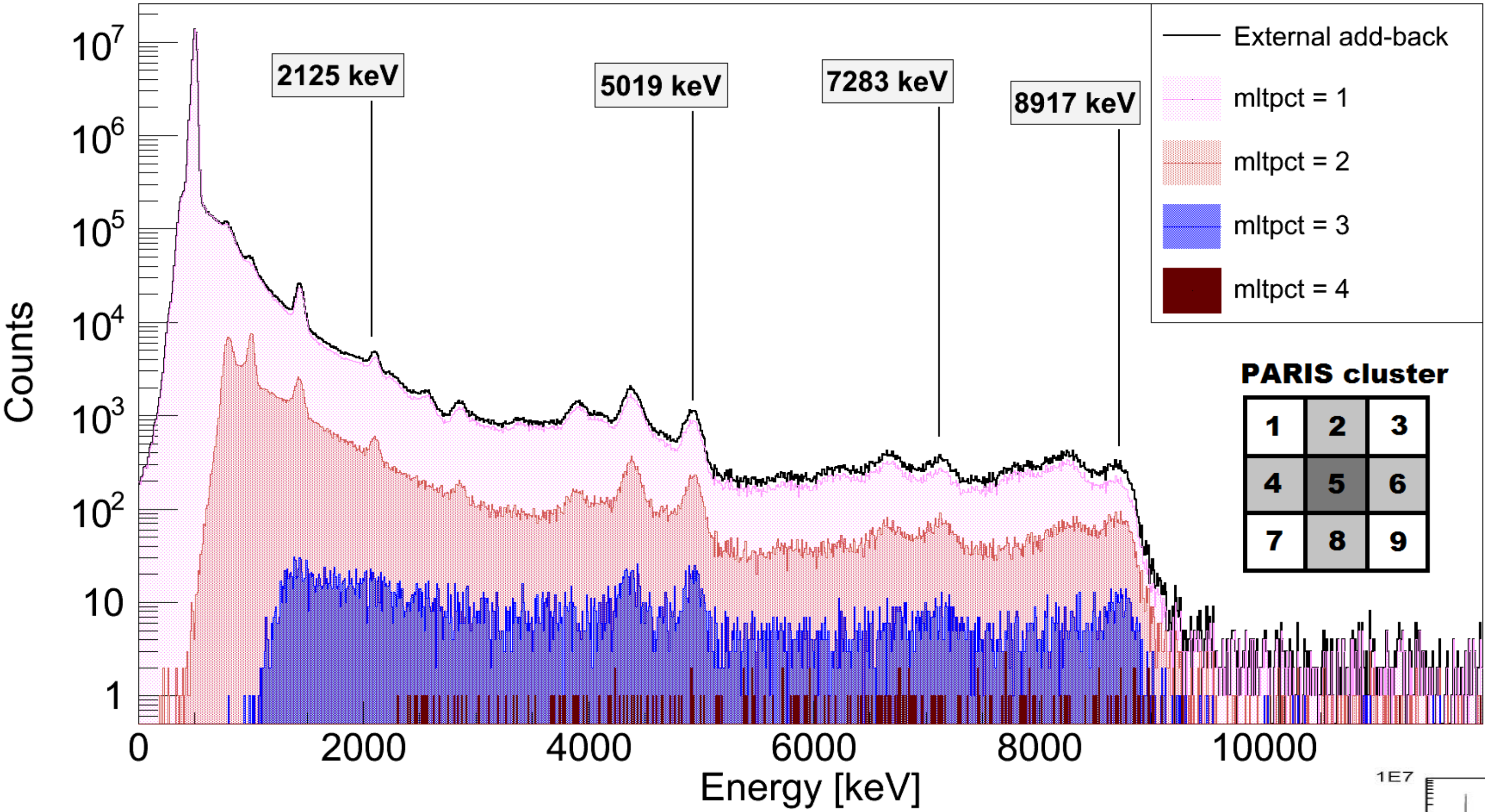




@ 18 and 22 MeV

(see C. Ghosh et al., JINST 11 P05023 (2016))

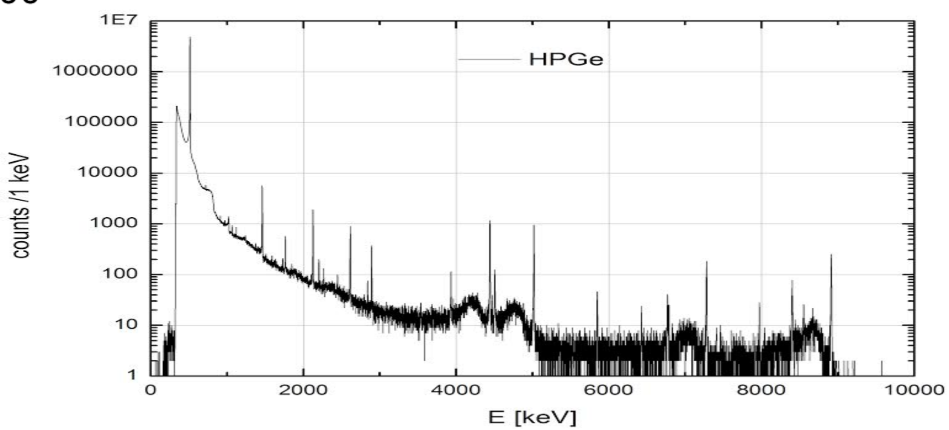
the Paris performances : using analog electronics (BaFPro module from MILANO)



ELBE facility, Dresden 10-12 December, 2013
Nuclear Resonance Fluorescence experiment (Mazumdar, Maj, Schwengner)

Electron beam converted into Bremsstrahlung (γ energy up to 15.6 MeV)

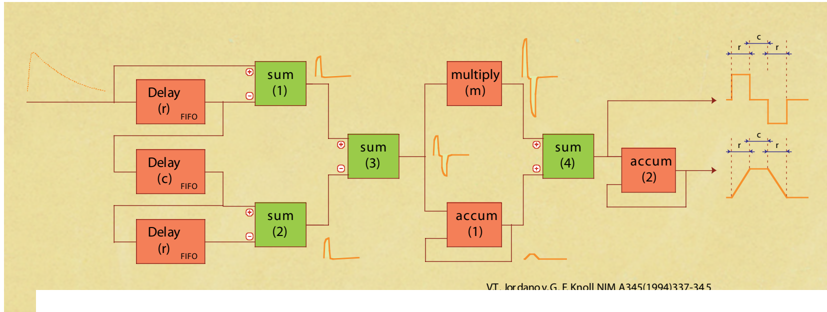
(see B. Wasilewska and al. in: O. Roberts, L. Hanlon, S. McBreen (Eds.) Applications of Novel Scintillators for Research and Industry, Iop Publishing Ltd, Bristol, 2015

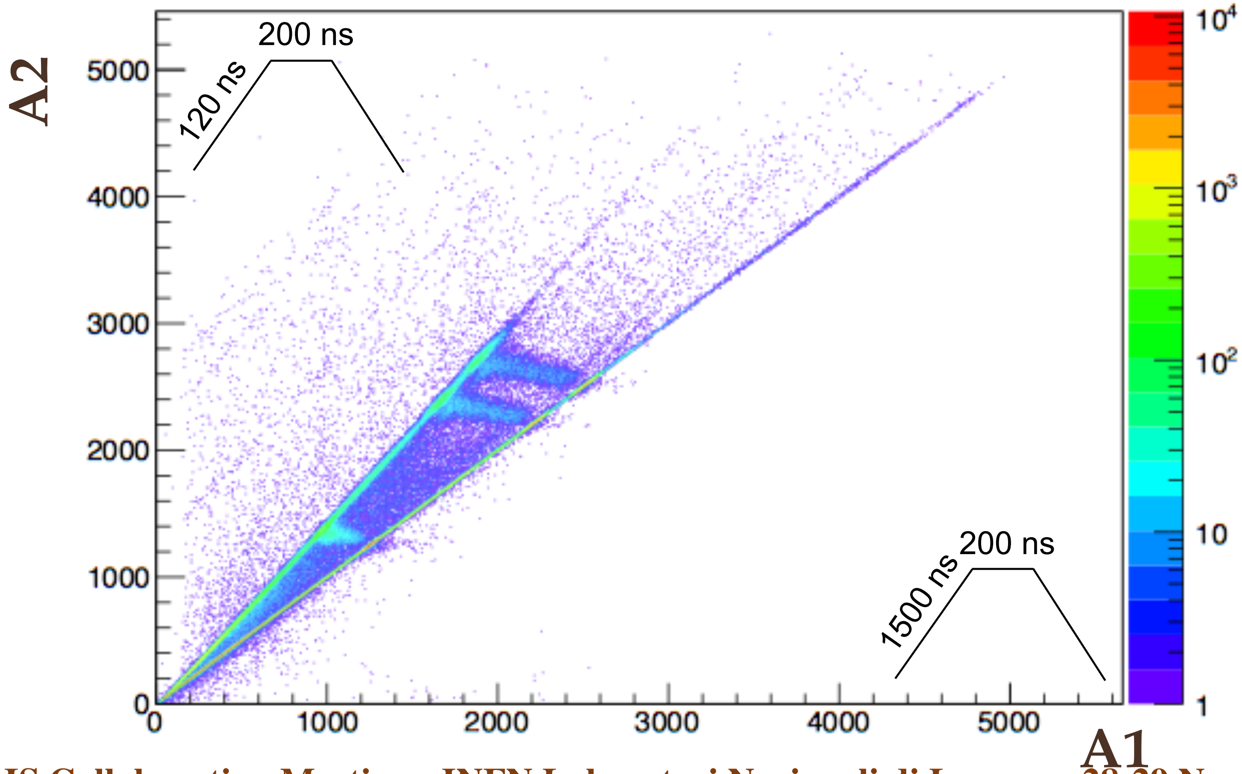


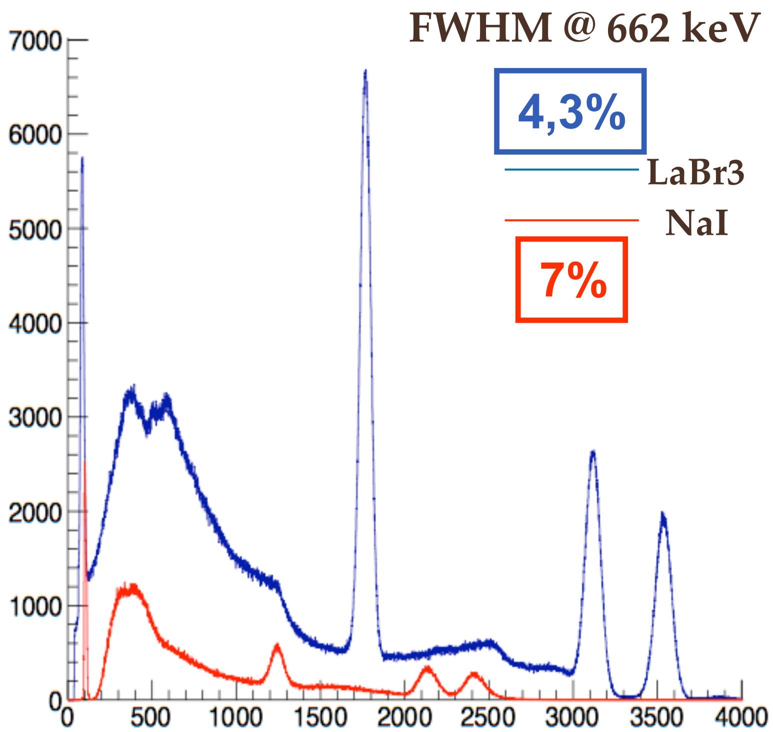
the Paris performances : using digital electronics

^{60}Co+^{137}Cs sources placed in front @ 7-40 kHz

- **Triggerless digital 100 MHz electronics TNT2 using an algorithm based on the Jordanov trapezoïdal method**

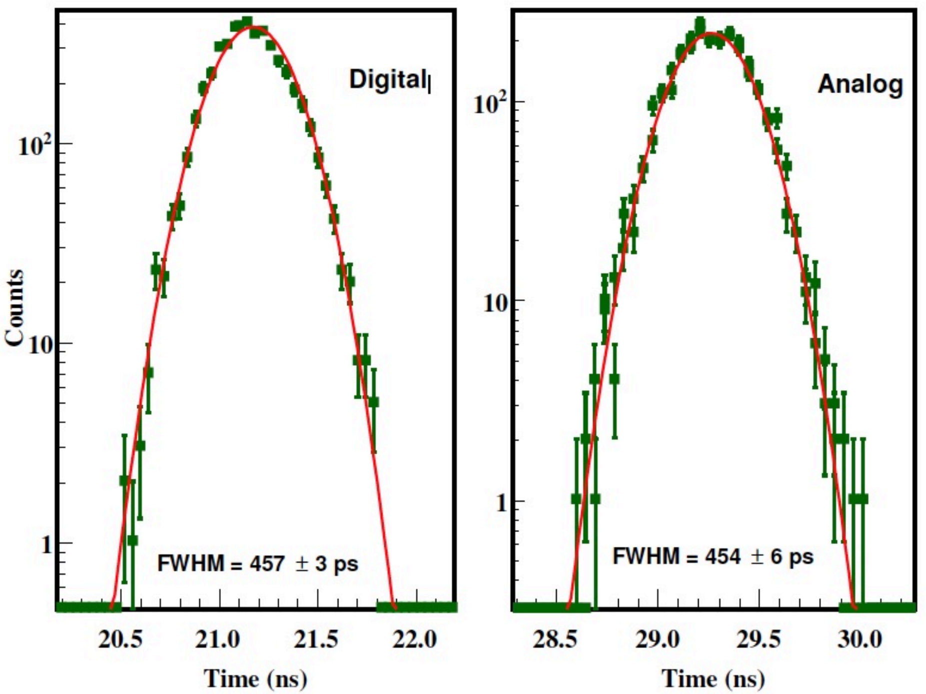






the Paris performances : time resolution

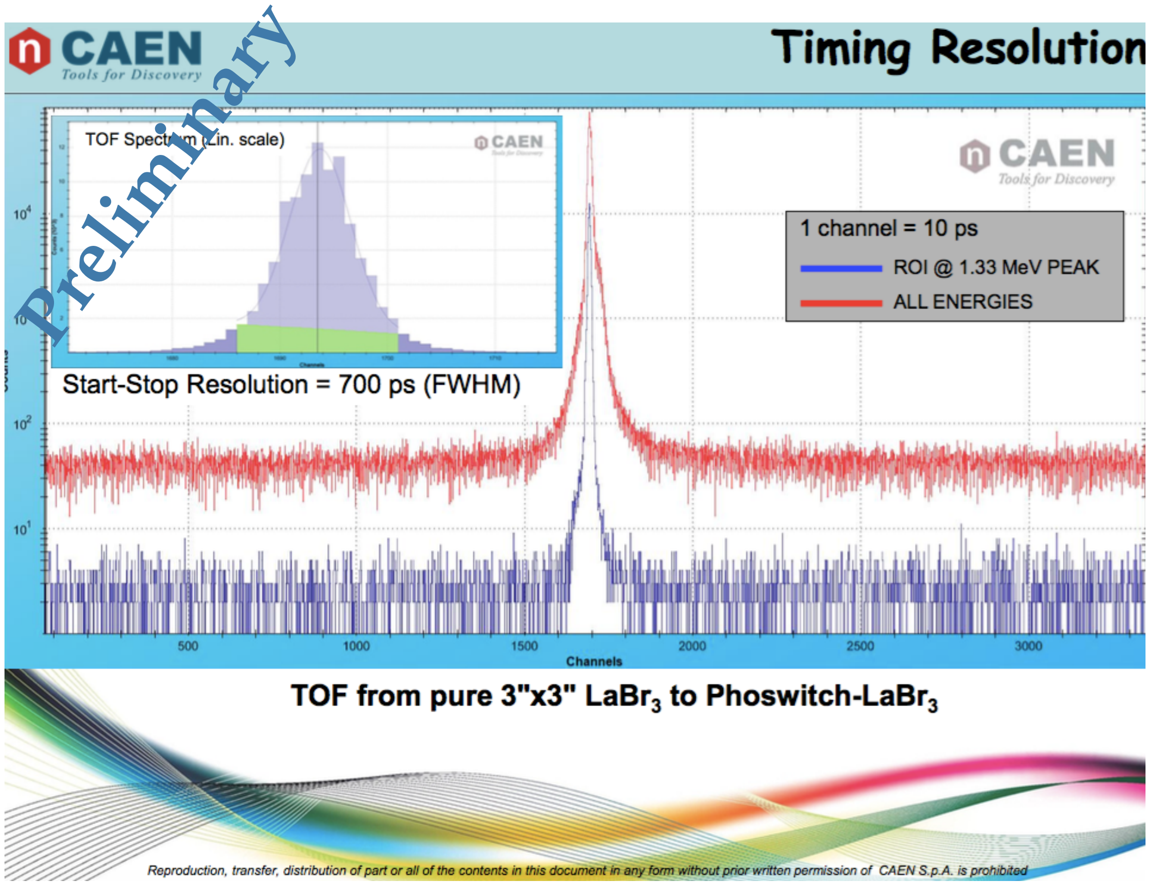
(see C. Ghosh et al., JINST 11 P05023 (2016))



done with V1751 CAEN digitizer 10 bits/1GHz

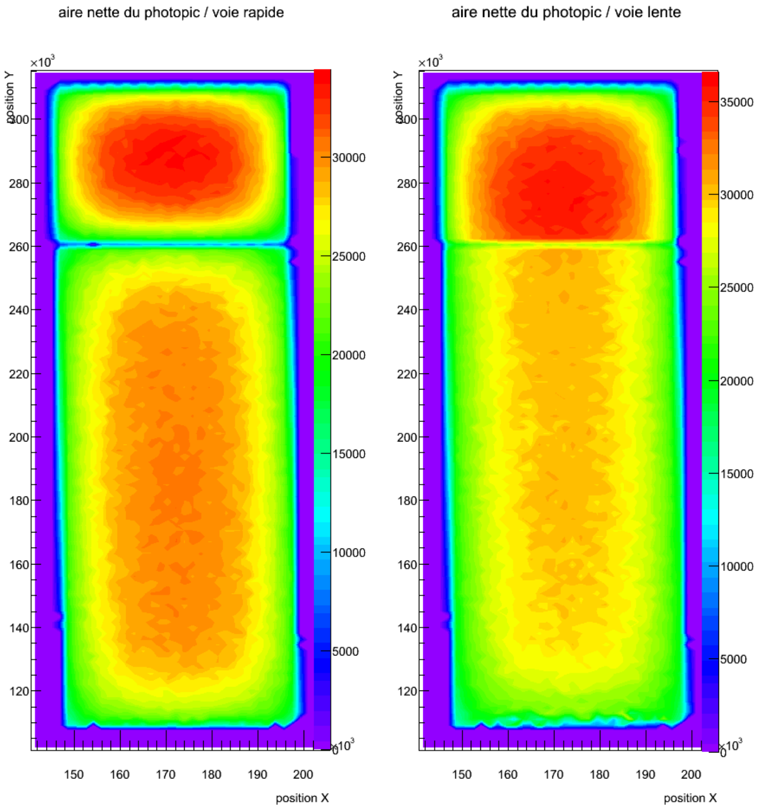
KRAKOW/MILANO/CAEN Collaboration

V1730 digitizer 14 bits/ 250 MHz



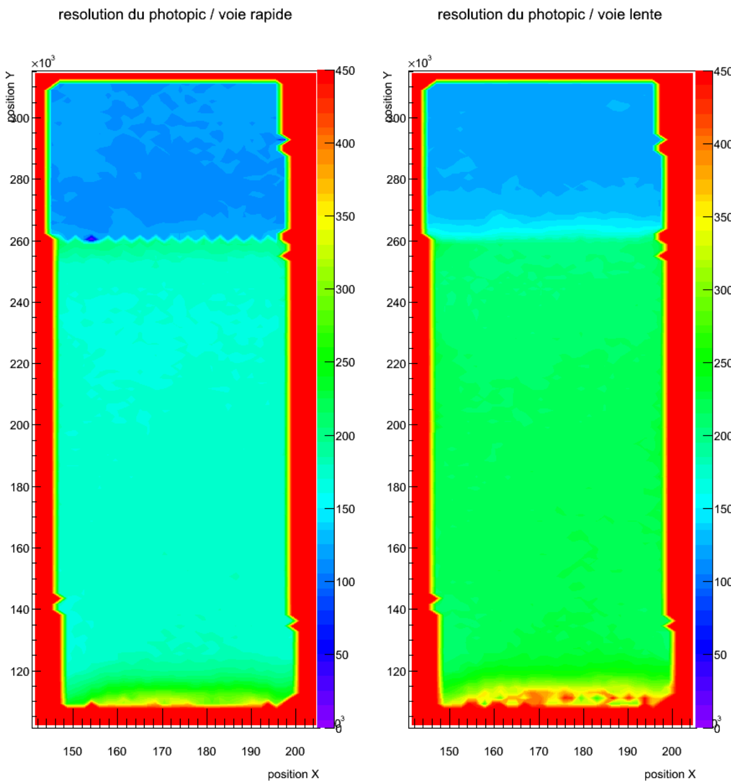
the scan of phoswiches : 1500 points

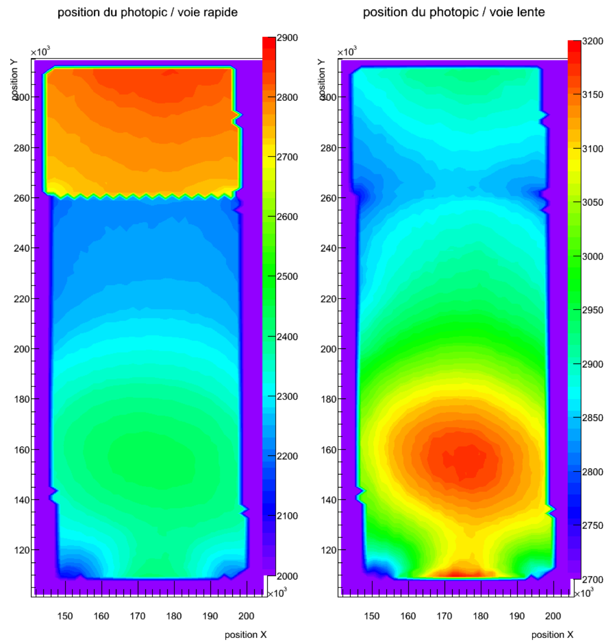
thanks to the AGATA collaboration for the scanning table@IPHC



~efficiency

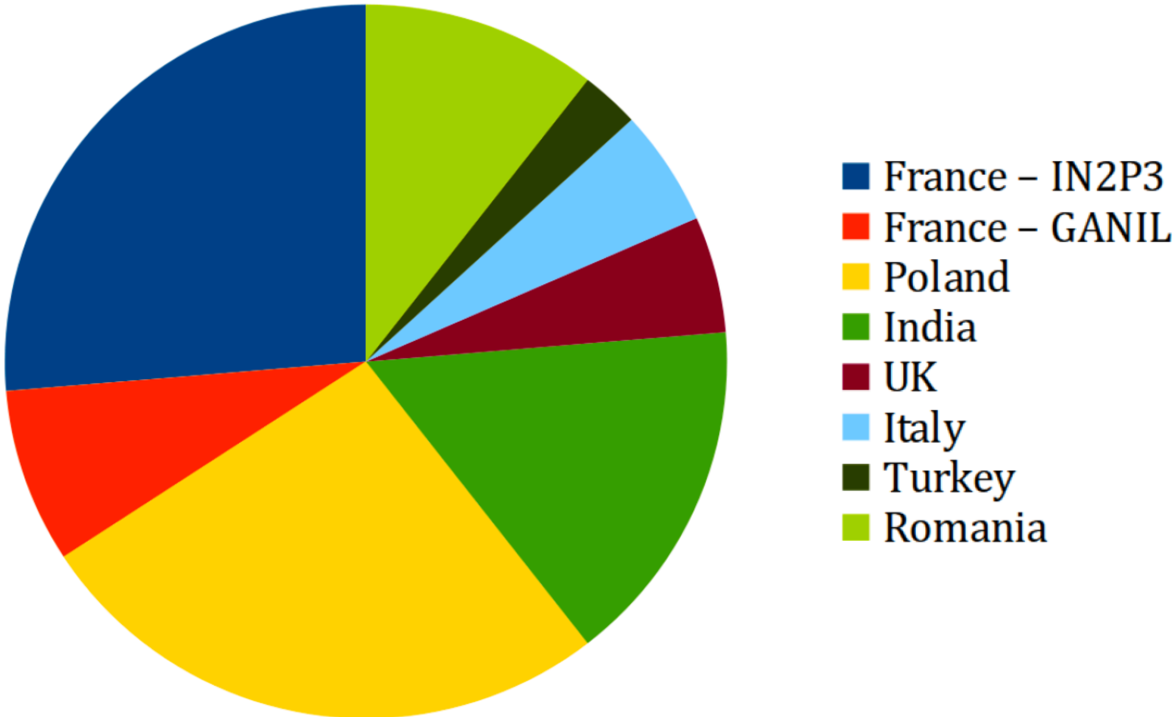
~resolution



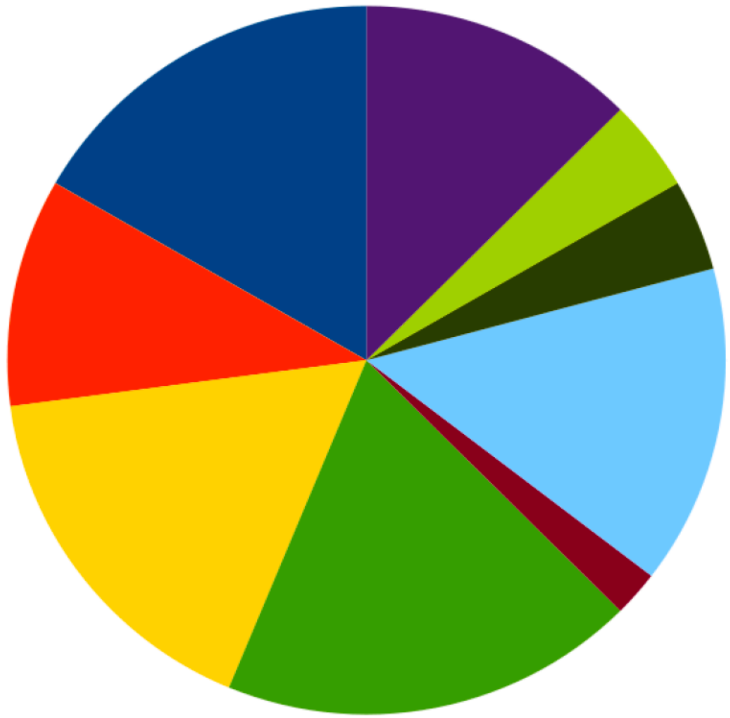


~light collection

the actual PARIS status : 53 detectors available (27 $LaBr_3$/NaI + 24 $CeBr_3$/NaI)



2012 - 2017



2018 - 2021

Courtesy of I. Matea - SC IN2P3 2019

the Paris performances :

energy resolution@662 keV

LaBr3 <FWHM> ~ 4.1% (ranging from 3,5 to 4.7%)

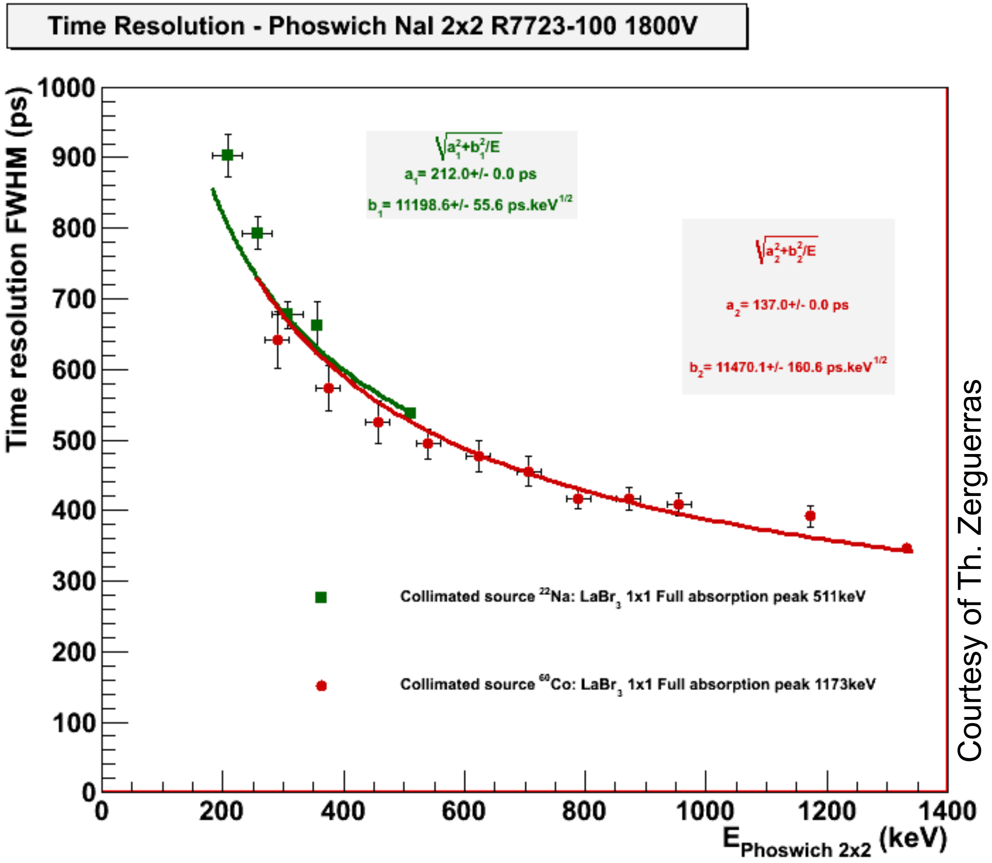
NaI <FWHM> ~ 7,8% (ranging from 7,1 to 9,4%)

CeBr3 <FWHM> ~ 4.8% (ranging from 3,9 to 5.8%)

NaI <FWHM> ~ 7,2% (ranging from 6,5 to 8.2%)

the Paris performances :

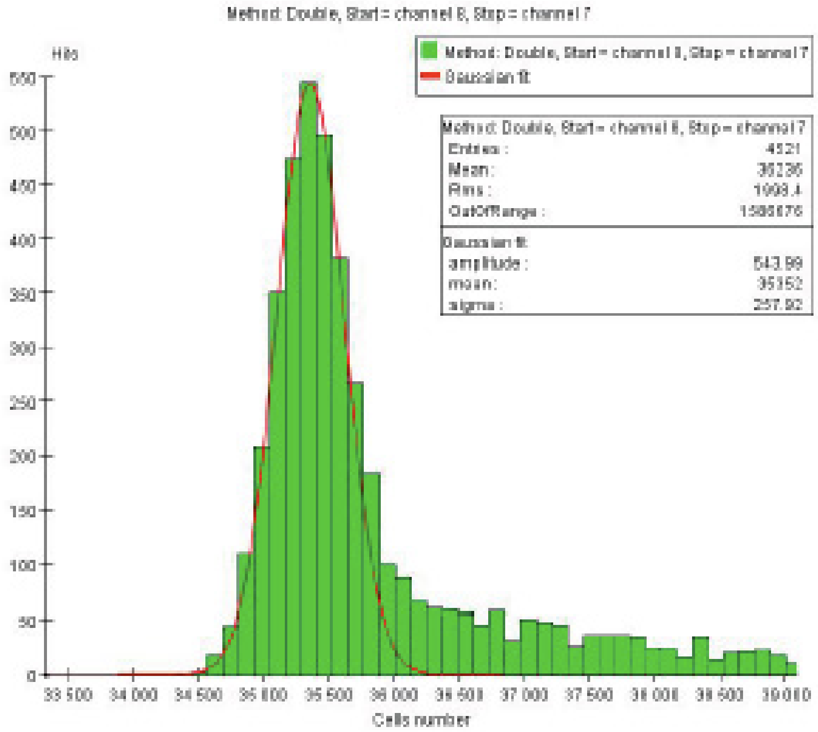
time resolution



Courtesy of Th. Zerguerras

Analog electronics

FWHM = 500 ps @ 551 keV
360 ps @ 1 MeV

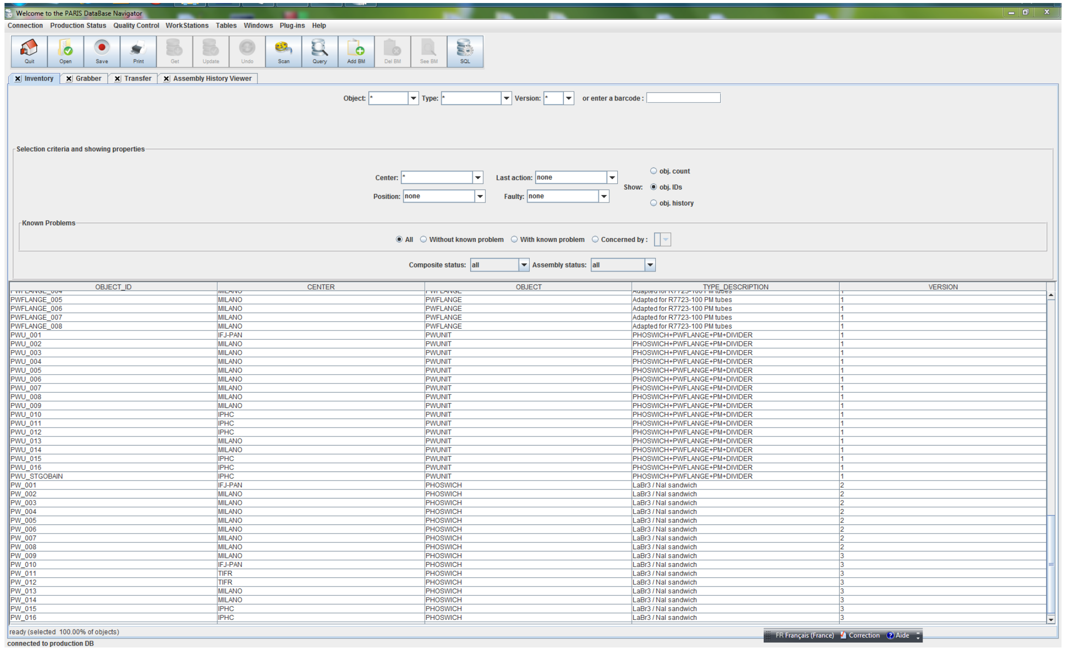


Courtesy of Ch. Bonnin

FWHM = 590 ps @ 1,33 MeV

the database @ IPHC

- we use the same R7723-100 PM and the same home-made voltage divider on a bench test to:
  - measure the LaBr3/CeBr3 and NaI energy resolution @ 662 keV
  - scan the full length of the PW unit to check the linearity @ 662 keV (thanks to the AGATA collaboration using the scanning table)
  - all informations are stored in a « AGATA-like » database (contact S.Kihel@IPHC)



PARIS tests

- Beam test in Krakow (GANAS detectors tests : PW LaBr3/LaCl3 + PARIS PW + large LaBr3 from Milano) from 13th to 28th of March 2013
- ORSAY experiment test in April 1st-8th 2013 @ Tandem ALTO : one cluster
- ELBE Rosendorf test in November 2013 : one cluster
- Many tests @ MILANO to optimize the PARISPro module

  @ KRAKOW to define a new digital electronics

  @ STRASBOURG with AmBe source and DT5730 digitizer

  @ VAMOS to see the effect of VAMOS magnetic field

Overview

- General presentation of PARIS detector and its characteristics
- **few words on simulation/shielding working close to an electromagnetic field**
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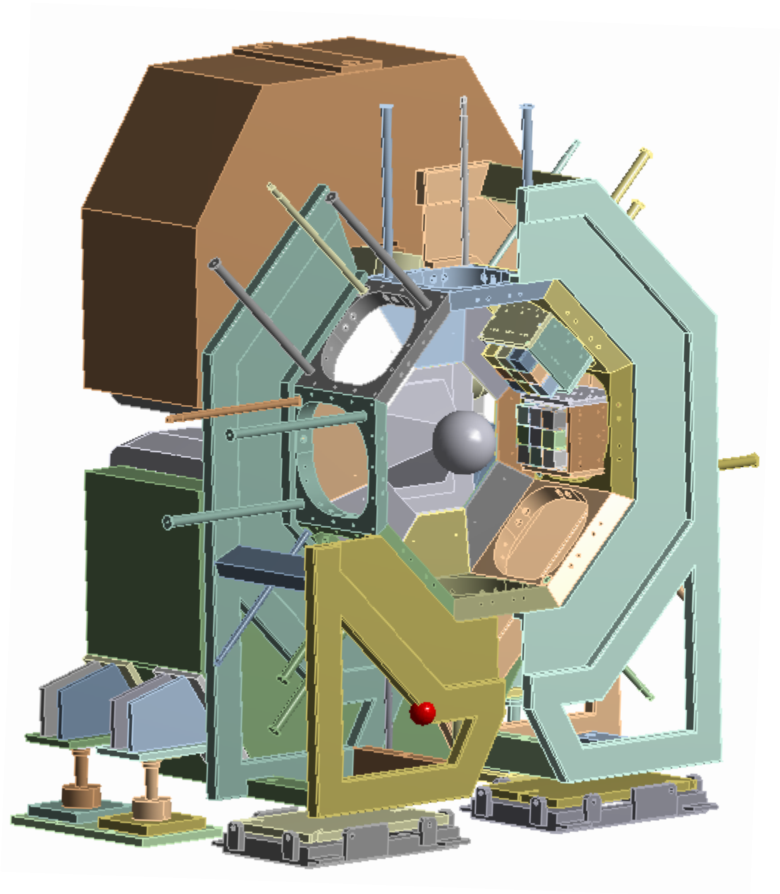
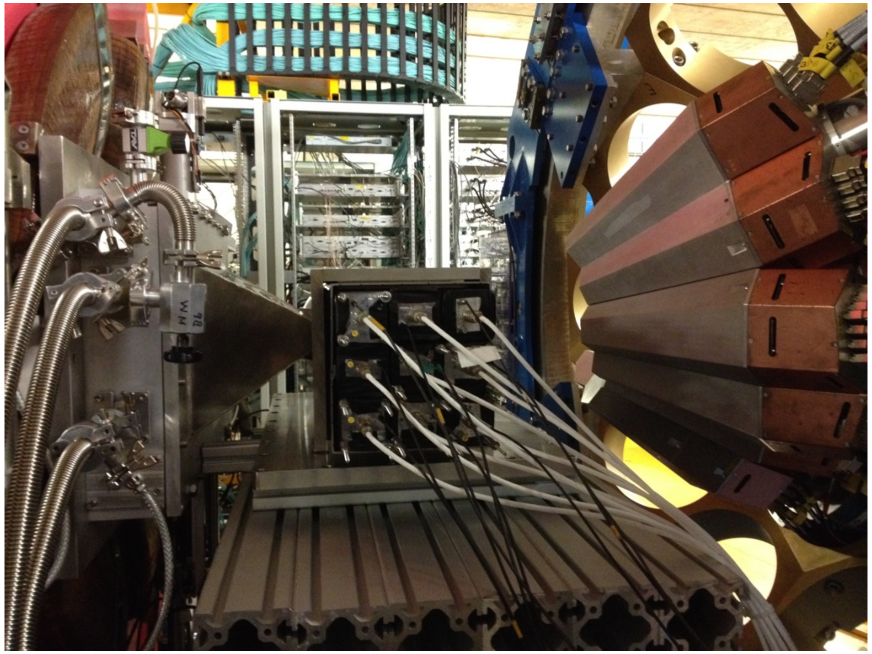
PARIS experiments @ GANIL/VAMOS & AGATA

Needs of test @ VAMOS to see the effect of VAMOS magnetic field

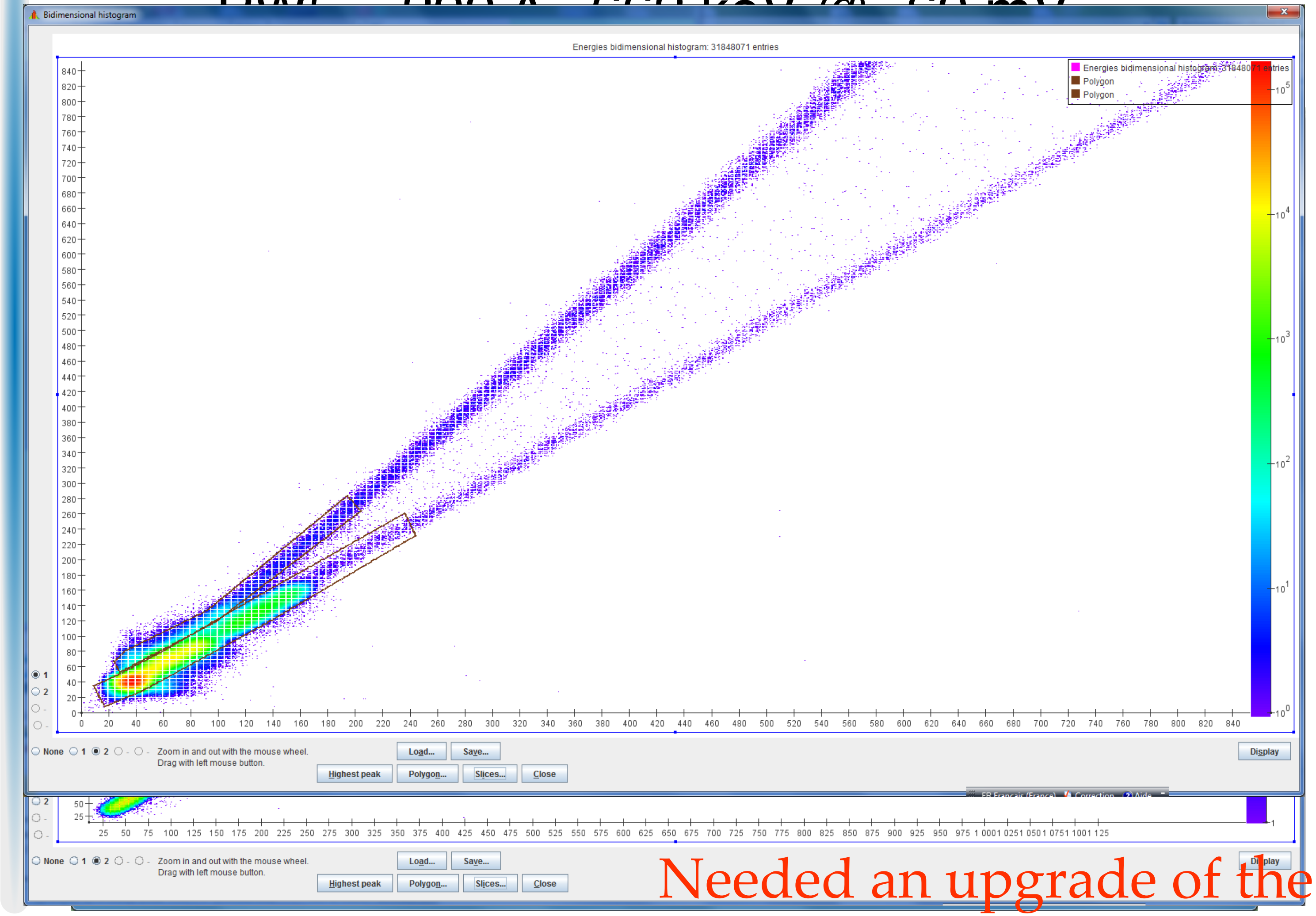


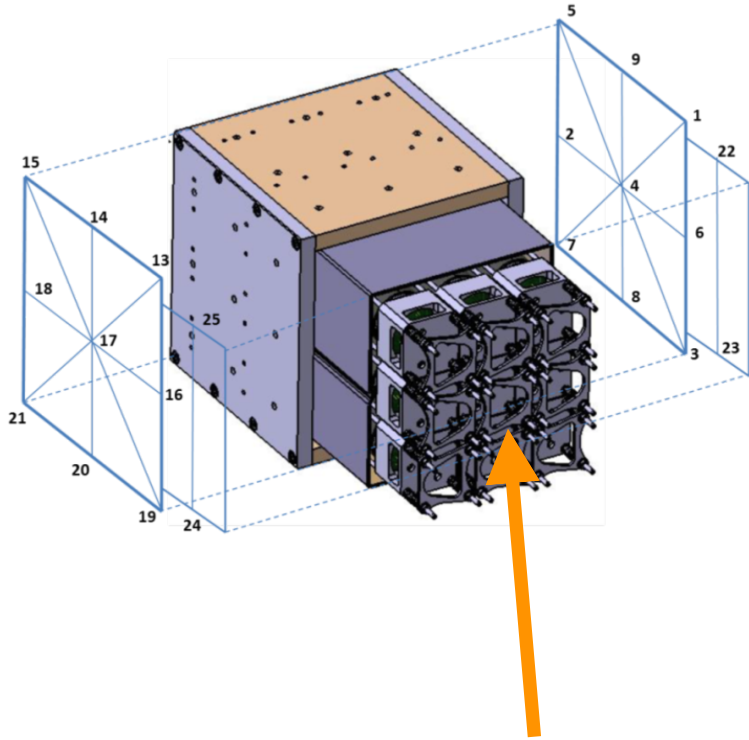


*(Courtesy of **E. Bouquerel**, S. Kihel, Ph. Peaupardin, M. Krauth and M. Ciemala)*

(Courtesy of **E. Bouquerel**, S. Kihel, Ph. Peaupardin, M. Krauth and M. Ciemala)

PW5 – 300 A, 662 keV @ -60 mV

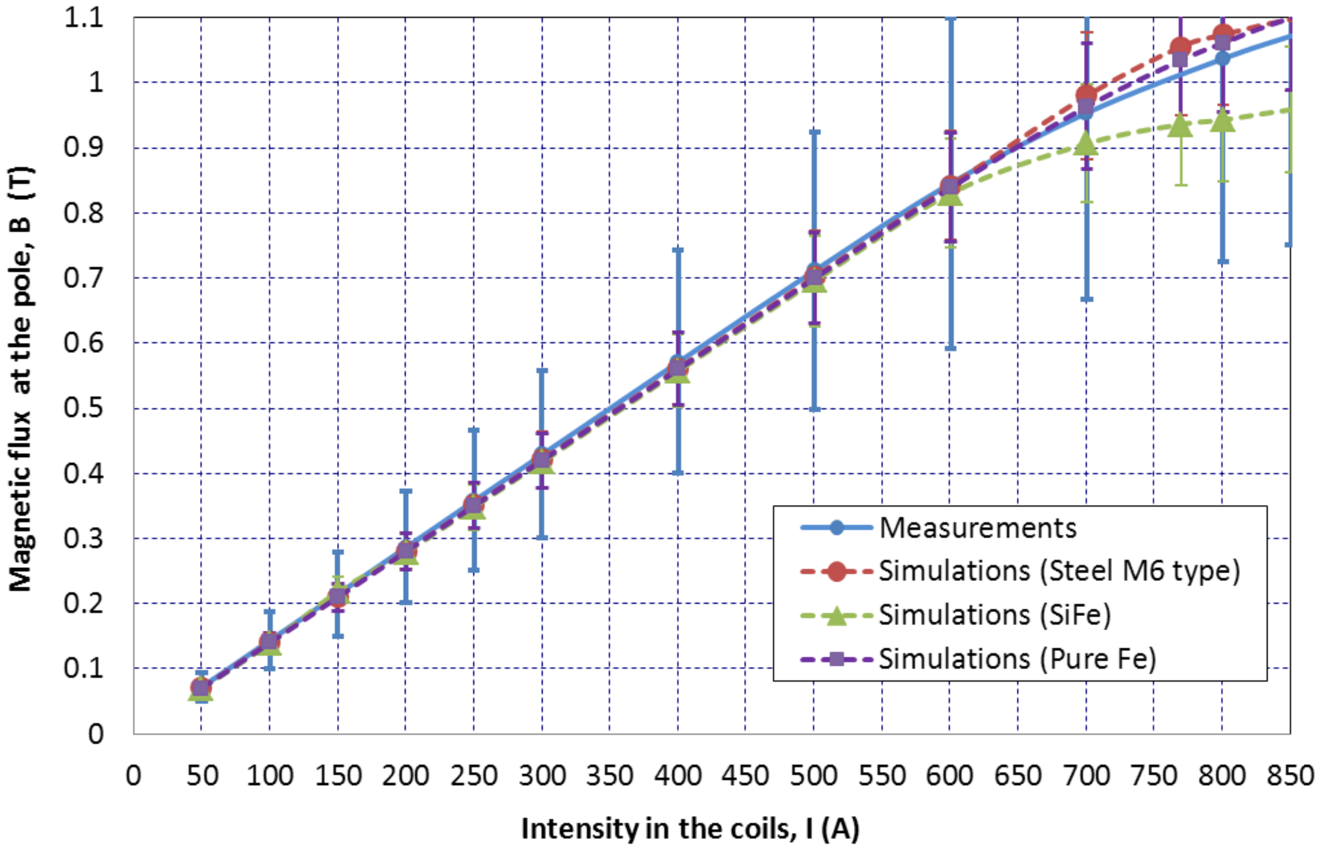


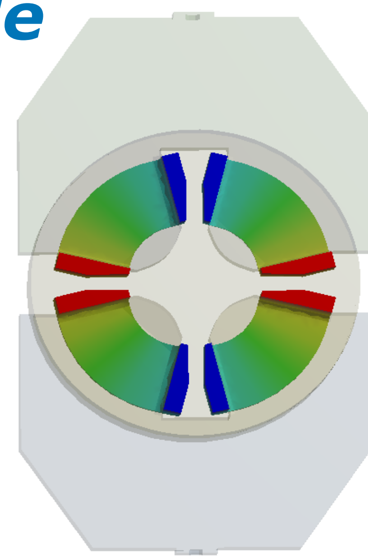


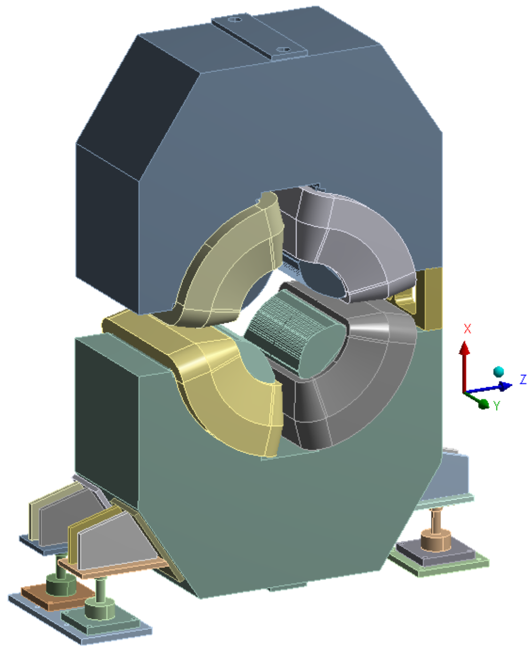
PW5

Needed an upgrade of the shield to be simulated

Excellent agreement between ANSYS simulations and magnetic field measurement @ VAMOS dipole

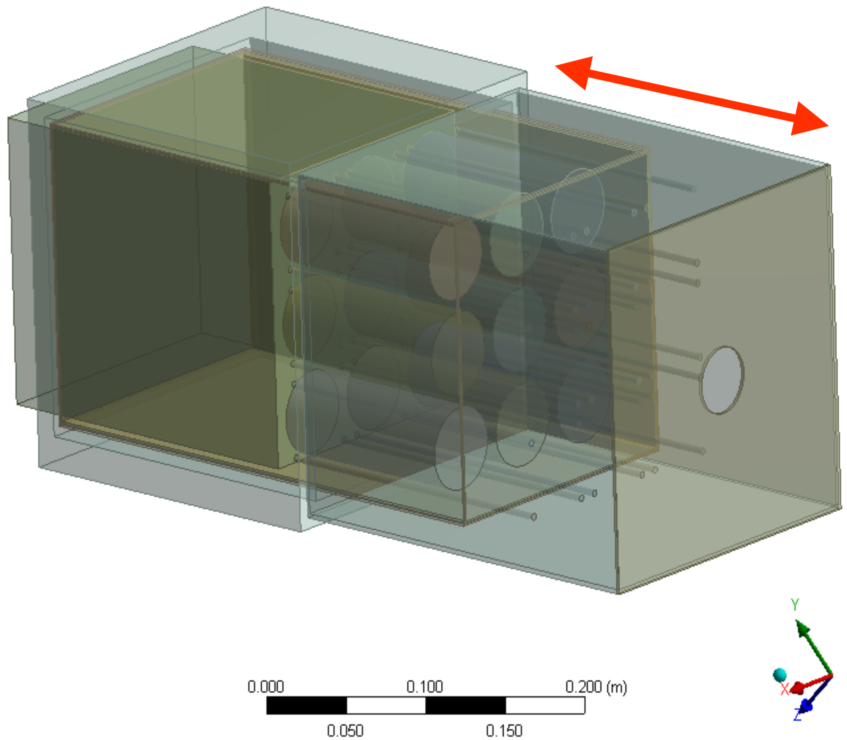




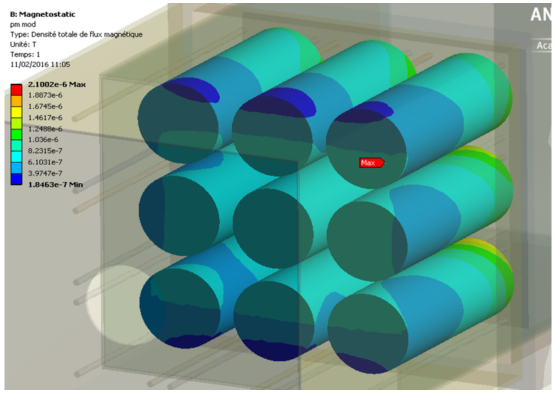


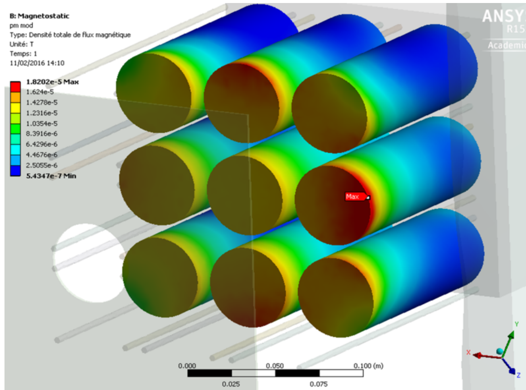
(Courtesy of E. Bouquerel)

- **Simulations modifying the actual shielding adding a second part with different thicknesses)**

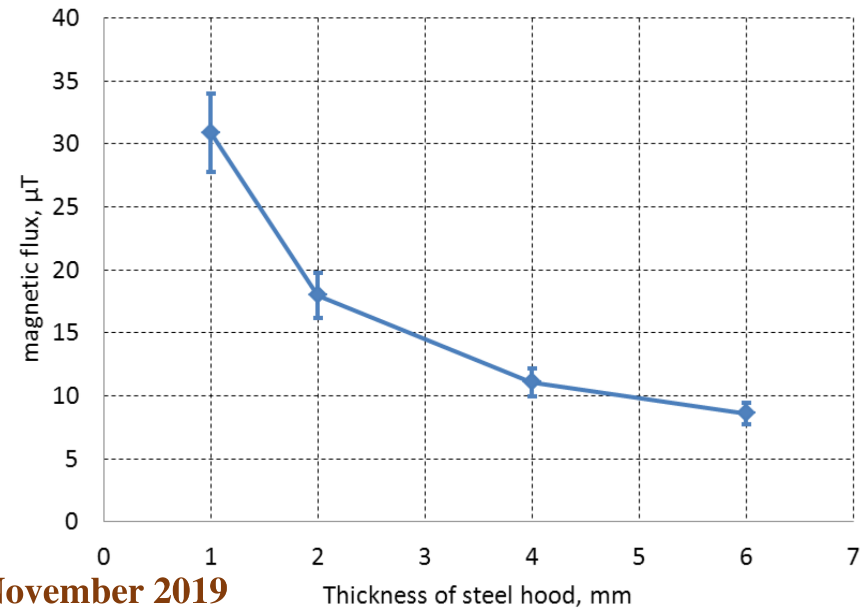


- **ANSYS Simulations modifying the shielding adding a second part with different thicknesses)**





0 ° | 45 °



With 2mm thick additional shield part :

Max. values obtained < Earth magnetic field

$2.1\ (0^\circ) < 18.2\ (45^\circ) < 47\ \mu T$

Overview

- General presentation of PARIS detector and its characteristics
- few words on simulation/shielding working close to an electromagnetic field
- **PARIS as a neutron detector ?**
- Conclusion

Preliminary results from « Prompt γ-rays as a probe of nuclear dynamics »

Aim of the experiment :

- Coupling *CORSET* with *ORGAM* and *PARIS* setups offers the unique opportunity of extracting details on the shell effects characterizing the two competitive processes, fusion-fission and quasifission, and which are deduced from the two-body kinematic method alone.
- Discrete γ-ray transitions to identify fragment (A,Z) and spin regions
- Gamma energy sum, multiplicity and angular distribution would give insight into entry point in E* and J

Preliminary results from « Prompt γ-rays as a probe of nuclear dynamics »

Experimental Setup: CORSET

$^{32}S + ^{197}Au \rightarrow ^{229}Am^{*}$, $E^{*} \approx 43$ MeV

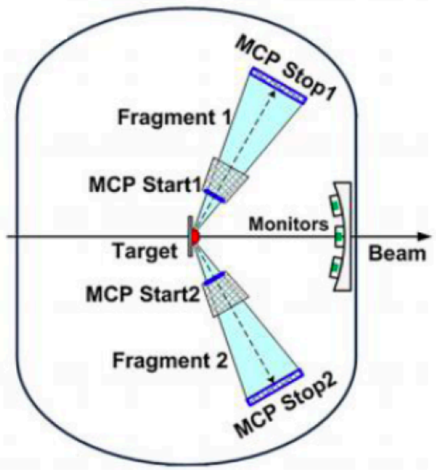
- CORSET:

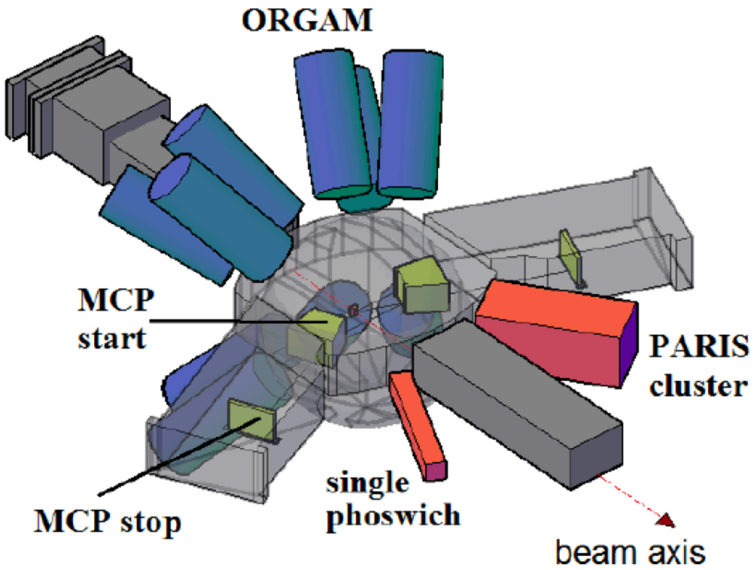
Measured parameters:

- ToF, X, Y

Extracted parameters :

- Velocity, energy, angles
- mass of fission fragments





Parameter	Value
The Coulomb barrier (in lab. sys)	167 MeV
Irradiation time	~4 days
Beam current	~90 nA
Collected statistics for fission fragments	274448
Excitation energy of the CN	~43 MeV

Courtesy of I.M. Harca

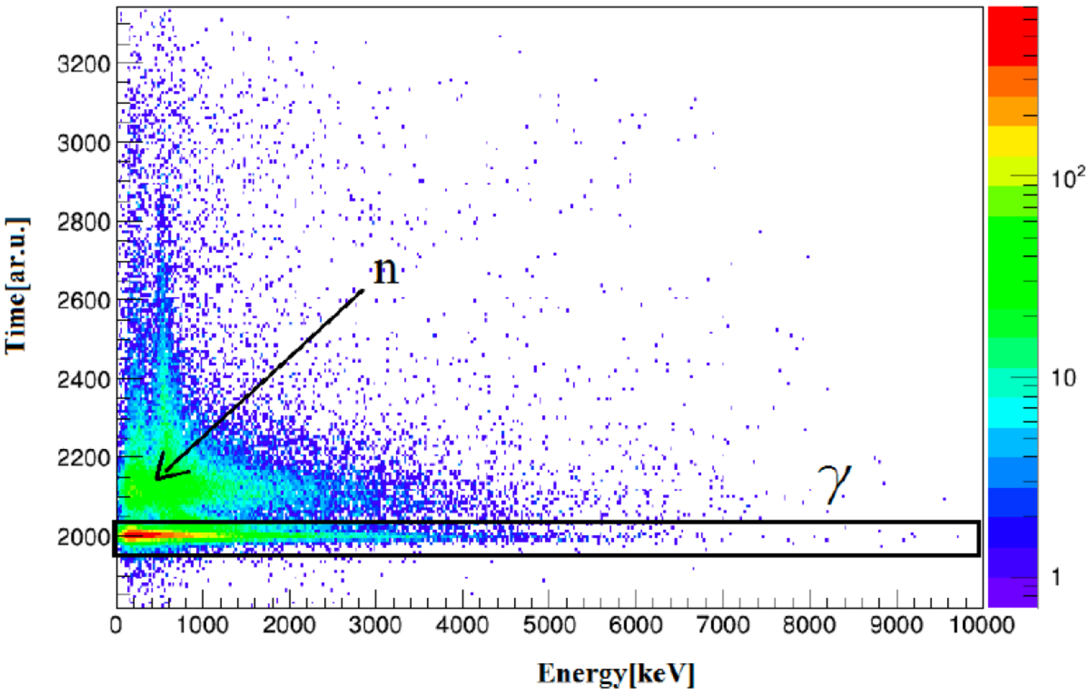
Preliminary results from « Prompt γ-rays as a probe of nuclear dynamics »

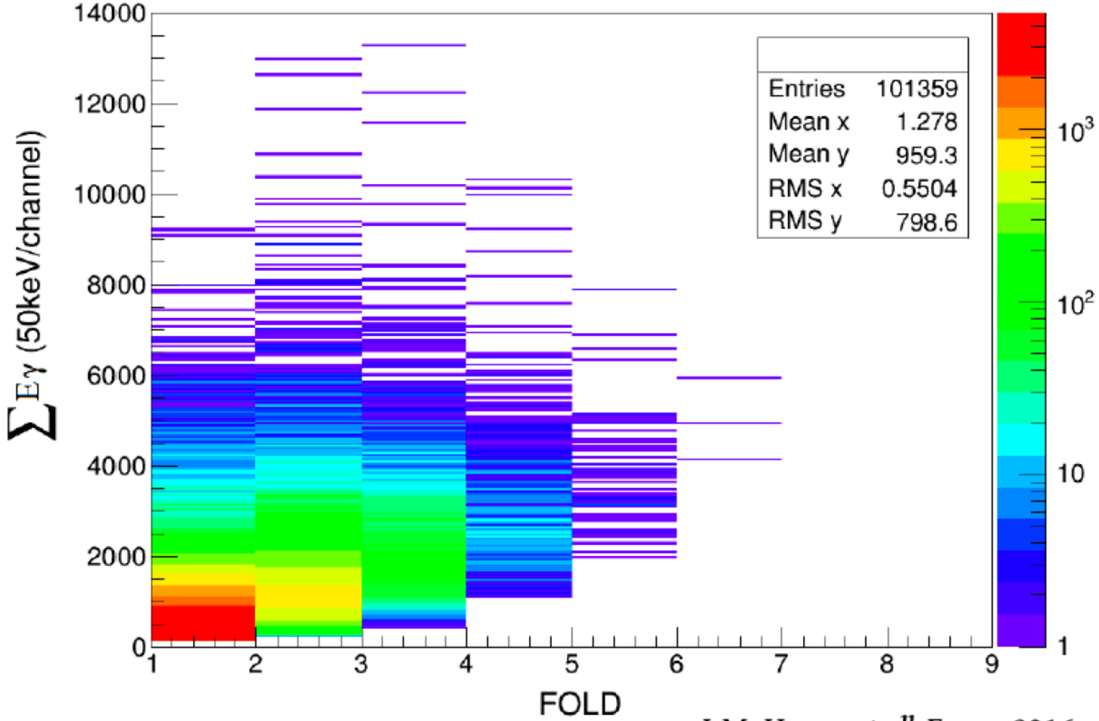
γ– Coincident with FF

PARIS

JINR FLNR Dubna

IPN ORSAY





I.M. Harca *et all.* Exon-2016 – Proceedings Of The International Symposium (isbn: 9789813226555)

- Good time resolution allowing discrimination of γ–rays against neutrons.
- Wide energy range.
- Able to accept high counting rate.

Courtesy of I.M. Harca

Keynote

Preliminary results from « Prompt γ-rays as a probe of nuclear dynamics »

- *average γ-ray multiplicity and spin distribution as function of the fission mass fragment*

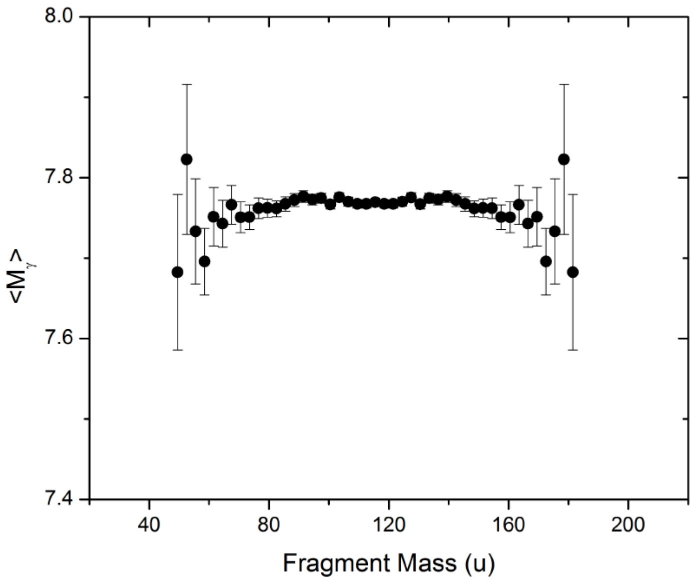


Fig. 5. The average γ-ray multiplicity vs the primary fragment mass. Symmetry was imposed.

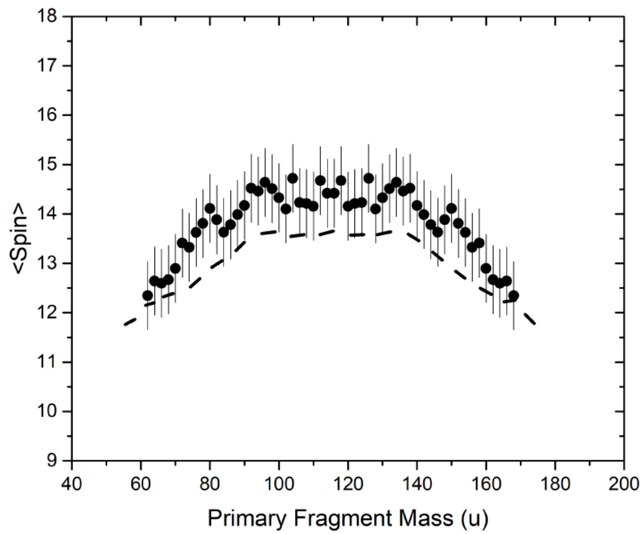


Fig. 6. The average total spin as a function of the primary fragments mass for the $^{32}S + ^{197}Au$ reaction as measured with ORGAM and PARIS (full circles) and calculated as described in the text (dashed line).

Extracted from I. Harca and al. Should be submitted soon

Preliminary results from « Prompt γ-rays as a probe of nuclear dynamics »

- *PARIS as « a neutron detector… » ?!*

Extracted from I. Harca and al. Should be submitted soon

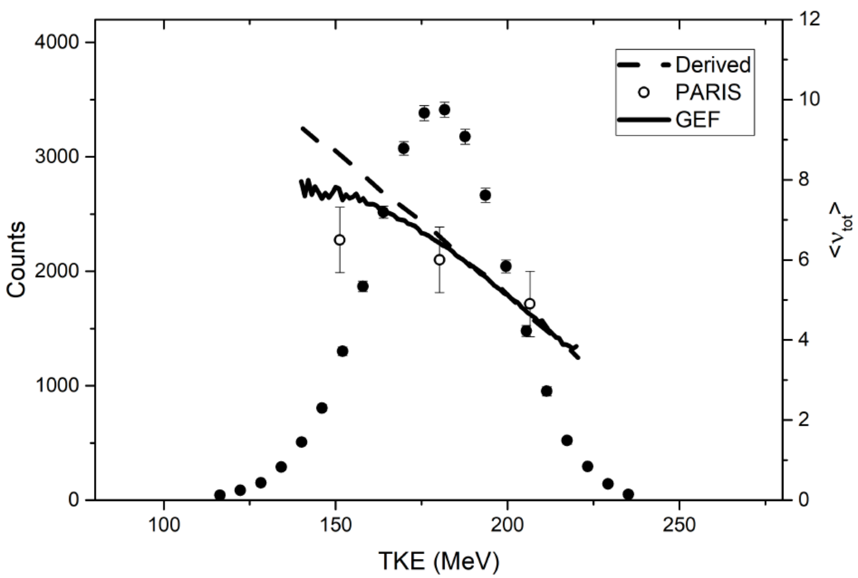


Fig. 4. The integral TKE distribution of the the fission-like fragments (circles). The average total neutron multiplicity as a function of the average TKE within the gates shown in 3 as measured by PARIS (open circles) compared to the average neutron multiplicity derived from the excitation energy of the fission-like fragments (as described in text, dashed line) and to the output of GEF (full line).

- *LaBr3 is sensitive to neutron*
- *need to qualify the neutron efficiency for LaBr » and CeBr3 detectors*
- *possibility to have information on the energy deformation at the scission point*

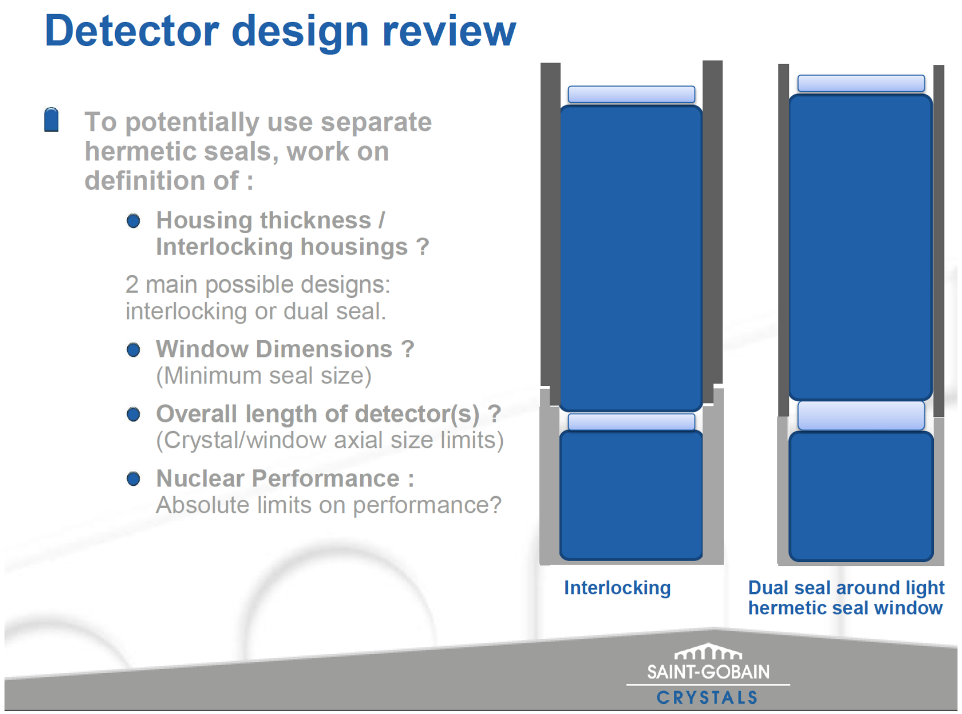
In conclusion …

- **the phoswich concept of PARIS works and have been validated by different tests/experiments**
- **mechanics for single crystal is ready, and mechanics for 4 clusters is ready too**
- **ANSYS simulations performed very valuable results and a gave a valuable design of the shielding for experiments close to VAMOS/other separators using magnets close to PARIS**

…

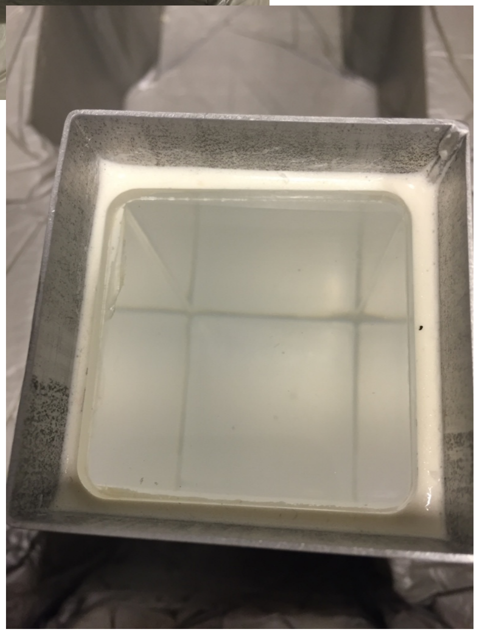
29 $LaBr_3$/NaI from Saint-Gobain (cost = 17,5 k€)

- 4 different designs to reach the optimum with a first delivery in 2007
- the actual design by adding a quartz window between the two crystals
- the last crystal are (Ce+Sr) doped LaBr3 B390 (and not B380) : gain of ~10% on energy resolution @662 keV



- prototypes/ production are manufactured in US (longer delay delivery)

24 CeBr3/NaI @ SCIONIX (cost 11 k€) starting from July 2016



- *Resolution of ~10% worst than the last B390 from Saint-Gobain*
- *CeBr3/NaI phoswich is a valuable solution for PARIS concept*

- *8 clusters should be ready/available by end 2021/2022*
- *investigation to measure PARIS cluster to neutron efficiency - planned in Dubna end of 2019 with ^{252}Cf source*
- *and PARIS is ready for future experiments (GANIL/AGATA, SPES/LNL, CBB Krakow, TIFR Mumbai, Alto, …)*

and thanks to

*F. Azaiez, P. Bednarczyk, J. Bettane, **E. Bouquerel**, C. Bonnin, A. Bracco, **S. Brambilla**, F. Camera, L. Charles, **M. Ciemała**, A. Czermak, **O. Dorvaux**, B. Fornal, A. Giaz, G. Hull, M. Jastrząb, D. Jenkins, **S. Kihel**, M. Kmiecik, M. Krauth, S. Kumar, S. Leoni, M. Lewitowicz, **A. Maj**, I. Matea, C. Mathieu, I. Mazumdar, K. Mazurek, A. Mentana, B. Million, **V. Nanal**, P. Napiorkowski, Ph. Peaupardin, Ch. Schmitt, O. Stezowski, **B. Wasilewska**, O. Wieland and **M. Zięgliński***

on behalf of the PARIS collaboration

IFJ PAN Krakow, Poland
IPHC Strasbourg, France
IPN Orsay, France
GANIL Caen, France
IPN Lyon, France
INFN - University of Milano, Italy
TIFR Mumbai, India
York University, UK
HIL Warsaw, Poland