Young Gammas Meeting
21 June 2024
Osservatorio Astronomico, Asiago

Istituto Nazionale di Fisica Nucleare

Characterization of new scintillator detectors for high-energy gamma-ray measurements

A. Giaz, INFN Sezione di Milano

Outline

- Introduction: why scintillators?
- **R&D on Scintillators**
  - PARIS SiPM readout
  - CLYC: fast neutron detection
- **Measurements of collective motions in nuclei with scintillators**
  - Isospin mixing in ^{72}Kr
  - ISGQR in ^{120}Sn
  - PDR in ^{58}Ni and ^{62}Ni

Why scintillators?

Large-volume scintillator detector arrays (**PARIS array**, **HECTOR+**, **CLYC array?**) are especially used in nuclear physics experiments for high-energy γ-ray measurements.

Main scintillator detector characteristics:

1. High Efficiency (high Z_{eff} and ρ);
2. Energy Resolution from 2.7% @ 662 keV;
3. Time Resolution < 1 ns;
4. Linearity for high-energy γ-rays;
5. Possibility to discriminate between gamma and neutrons.

R&D on Scintillators

PARIS SiPM readout

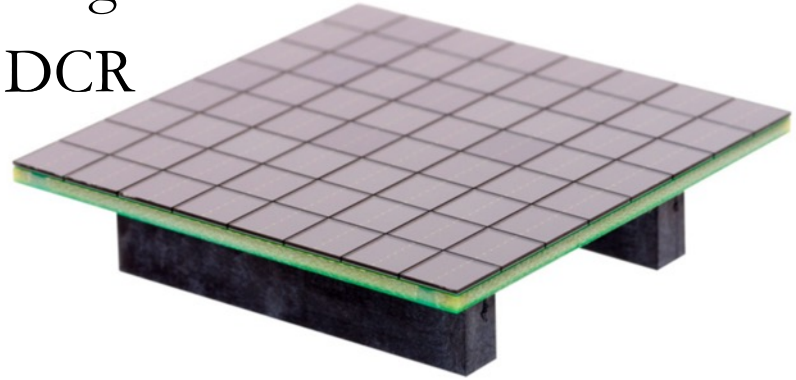
SiPM vs PMT

Advantages:

- Non sensitive to magnetic field
- No need of HV
- Mecchanical Compactness
- Single photon sensitivity

Disadvantages:

- Large area
- DCR



Advantages:

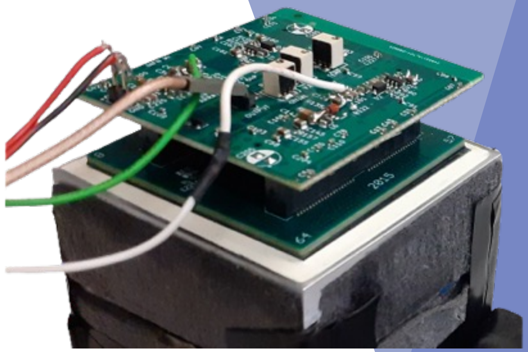
- Low DCR
- Large area
- Possibility of UV sensitivity

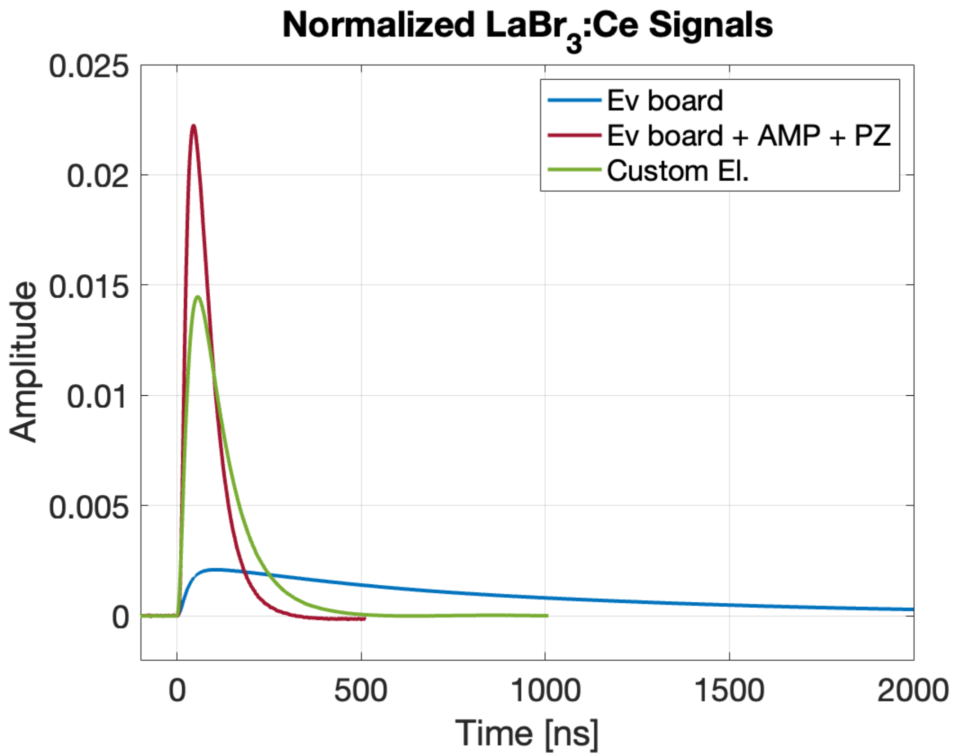
Disadvantages:

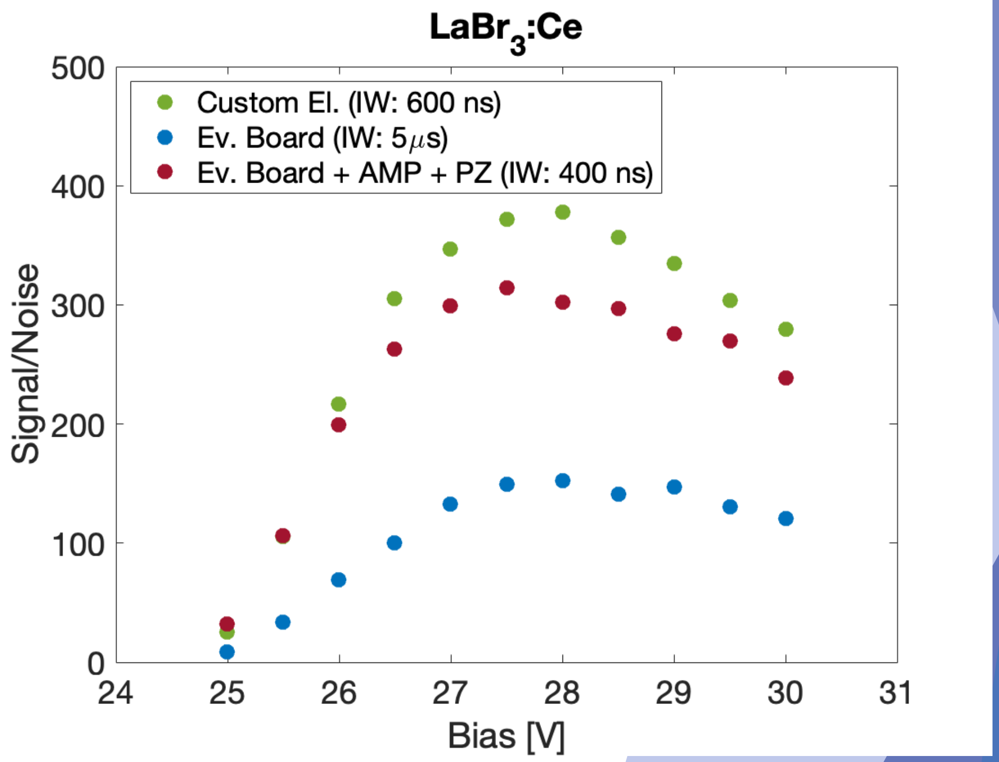
- Sensitivity to magnetic field
- Need of HV

SiPM readout for PARIS detectors

Readout electronics used for SensL SiPMs:







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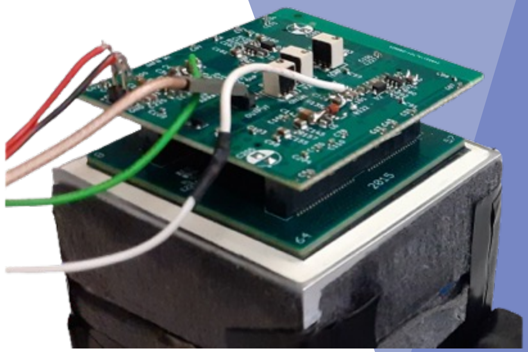

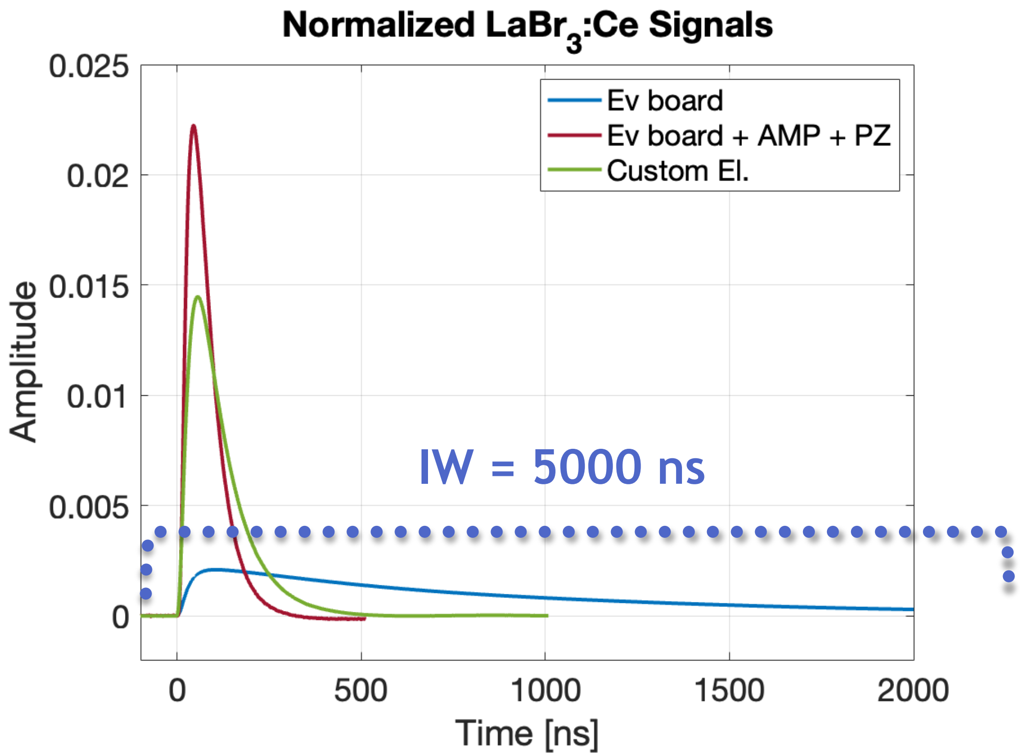

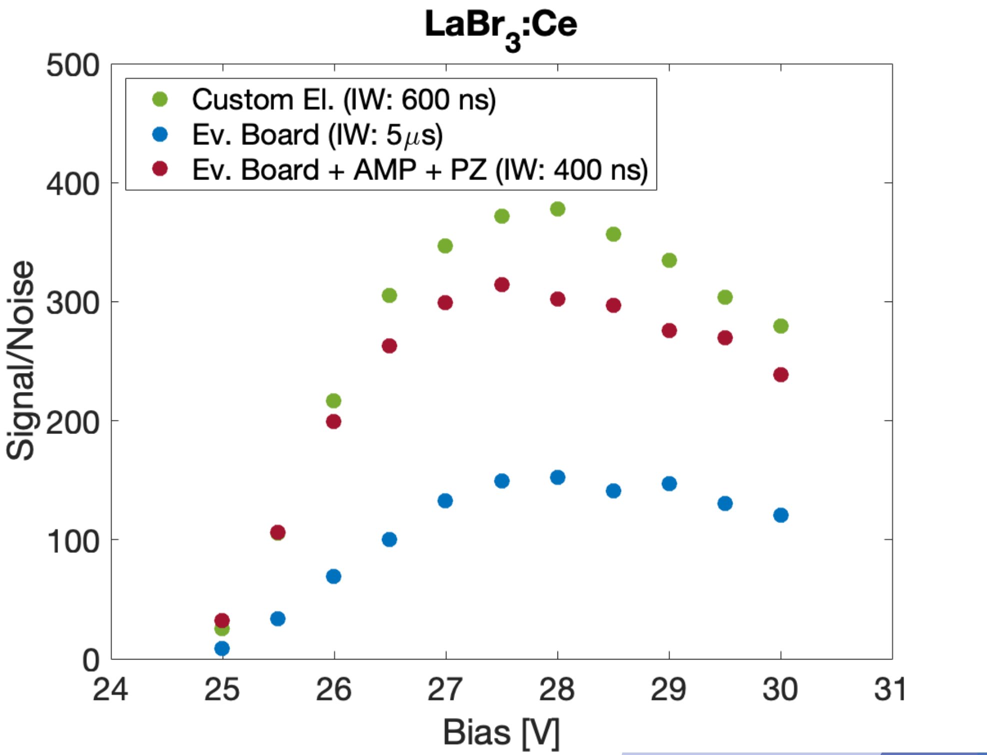

SiPM readout for PARIS detectors

Readout electronics used for SensL SiPMs:

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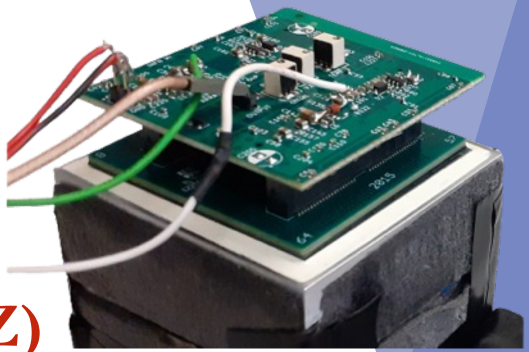
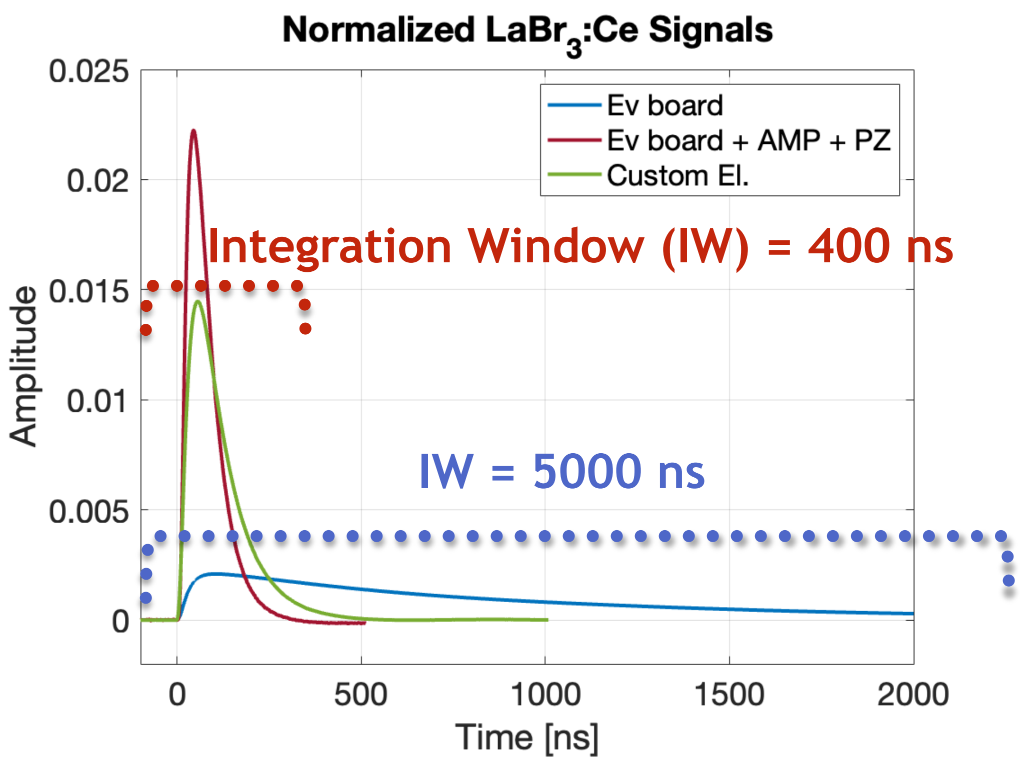
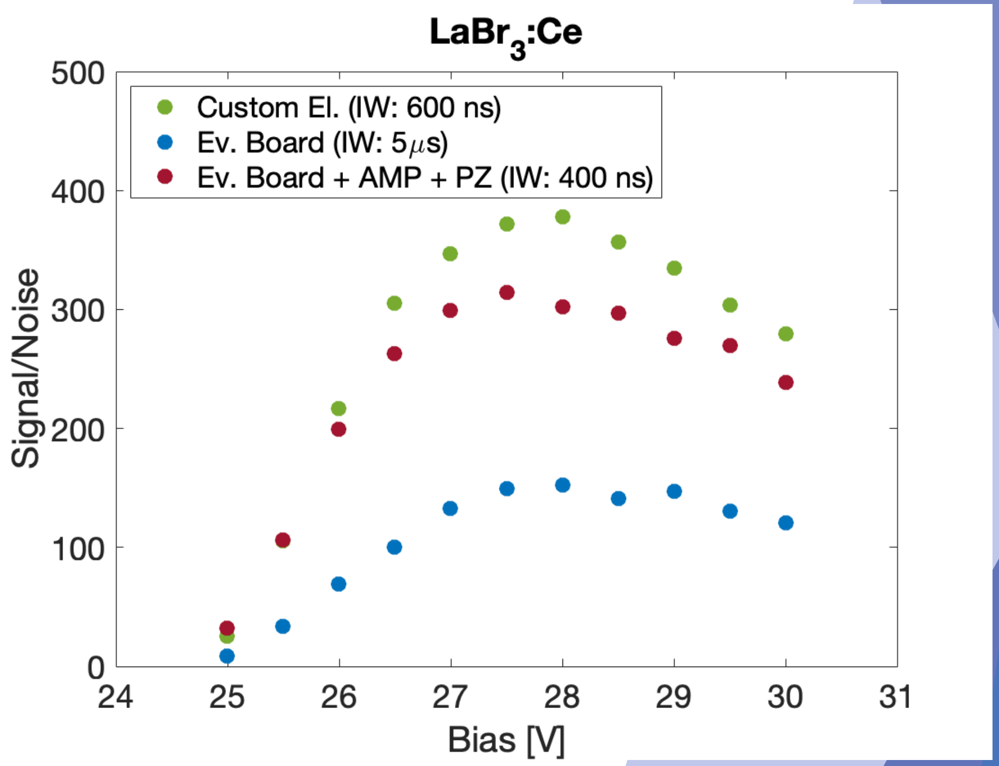
2. **SensL evaluation board + Amplification + Pole Zero (PZ)**







SiPM readout for PARIS detectors

Readout electronics used for SensL SiPMs:

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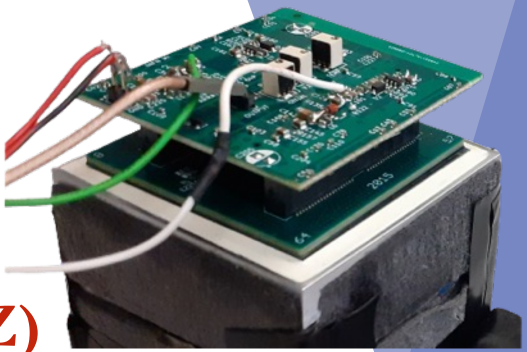
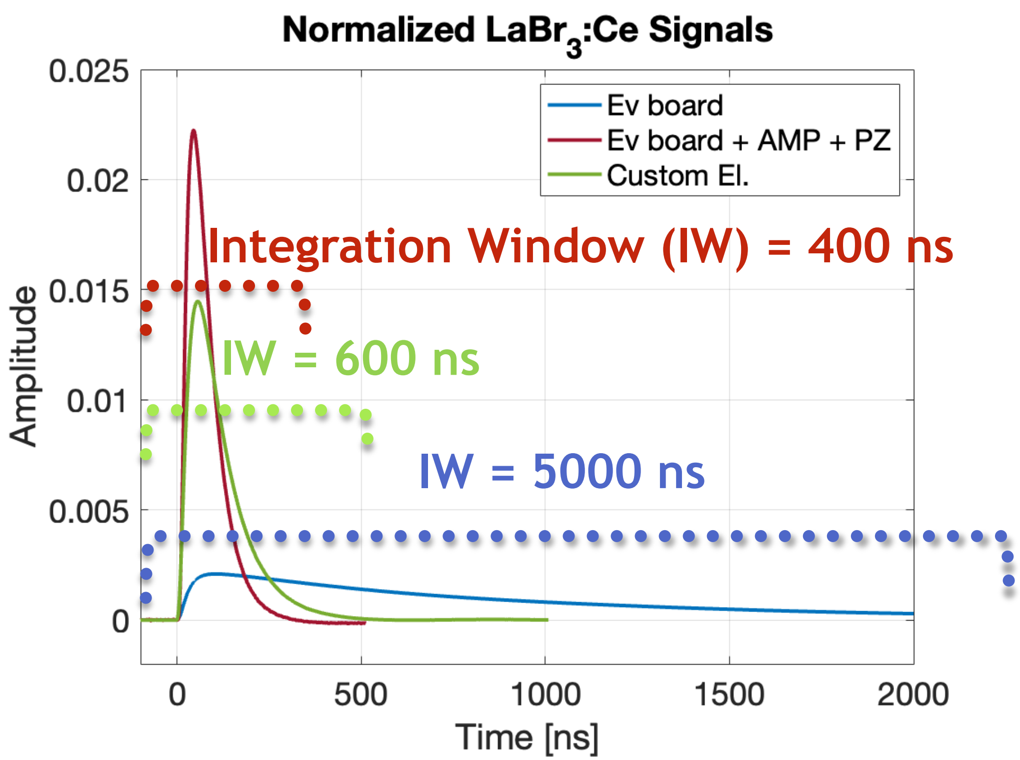
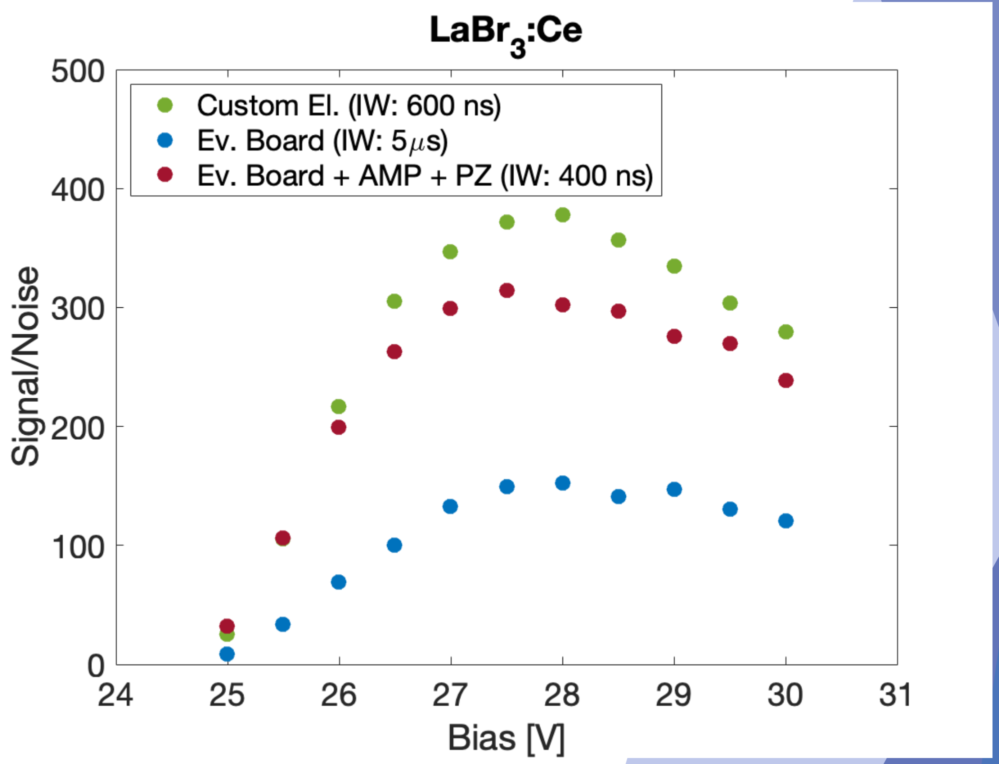
3. **Custom electronics**







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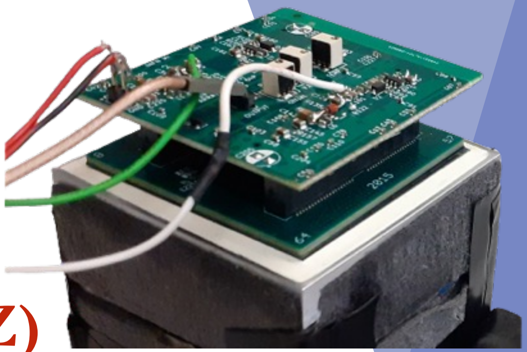
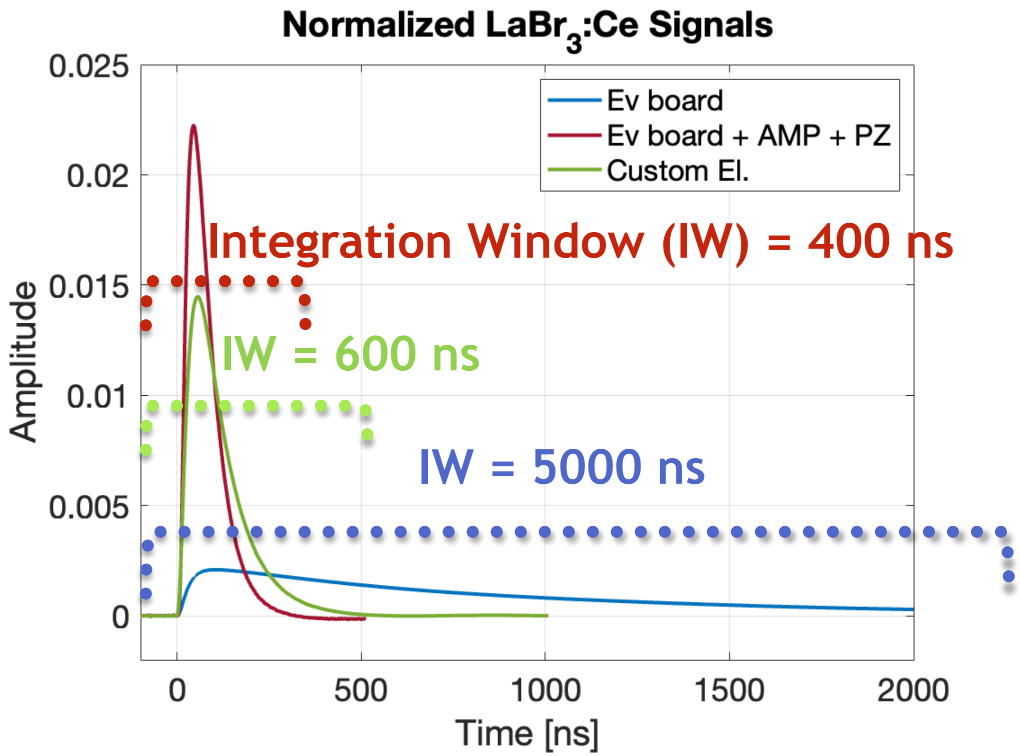
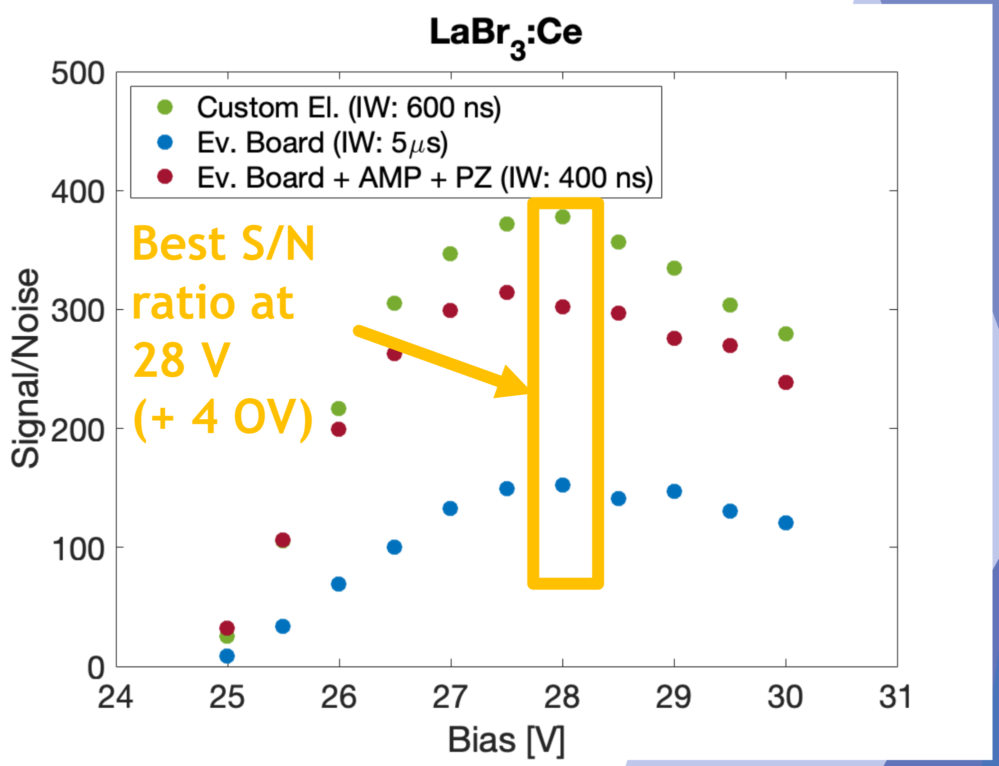
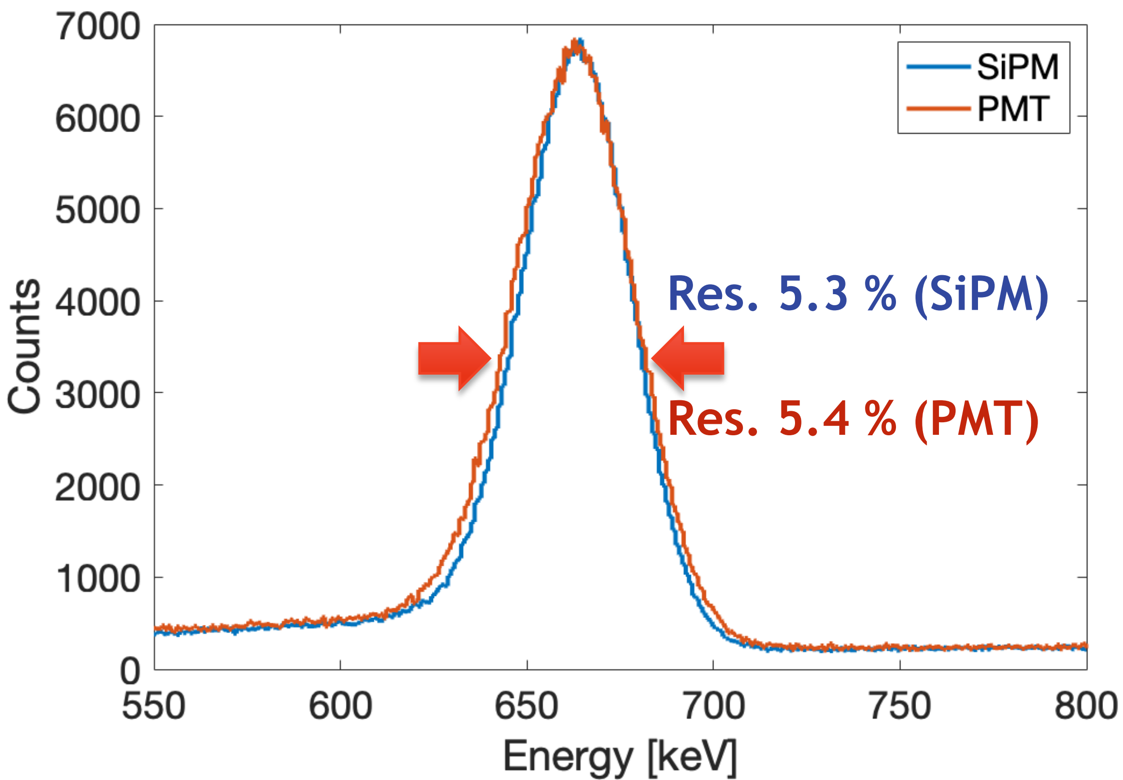






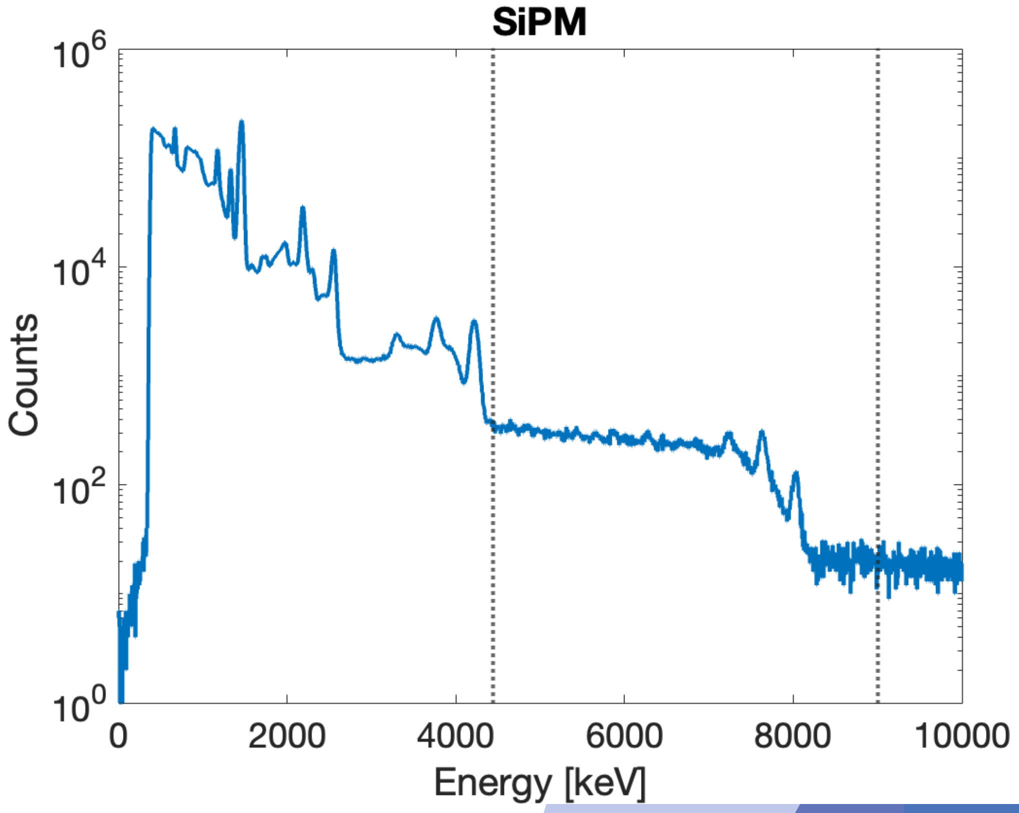
PARIS: SiPMs (I)

	PMT R13080-100	SiPM SensL
QE / PDE	38 %	44% (FF 75%)
Size	20.27 cm²	5 x 5 cm²



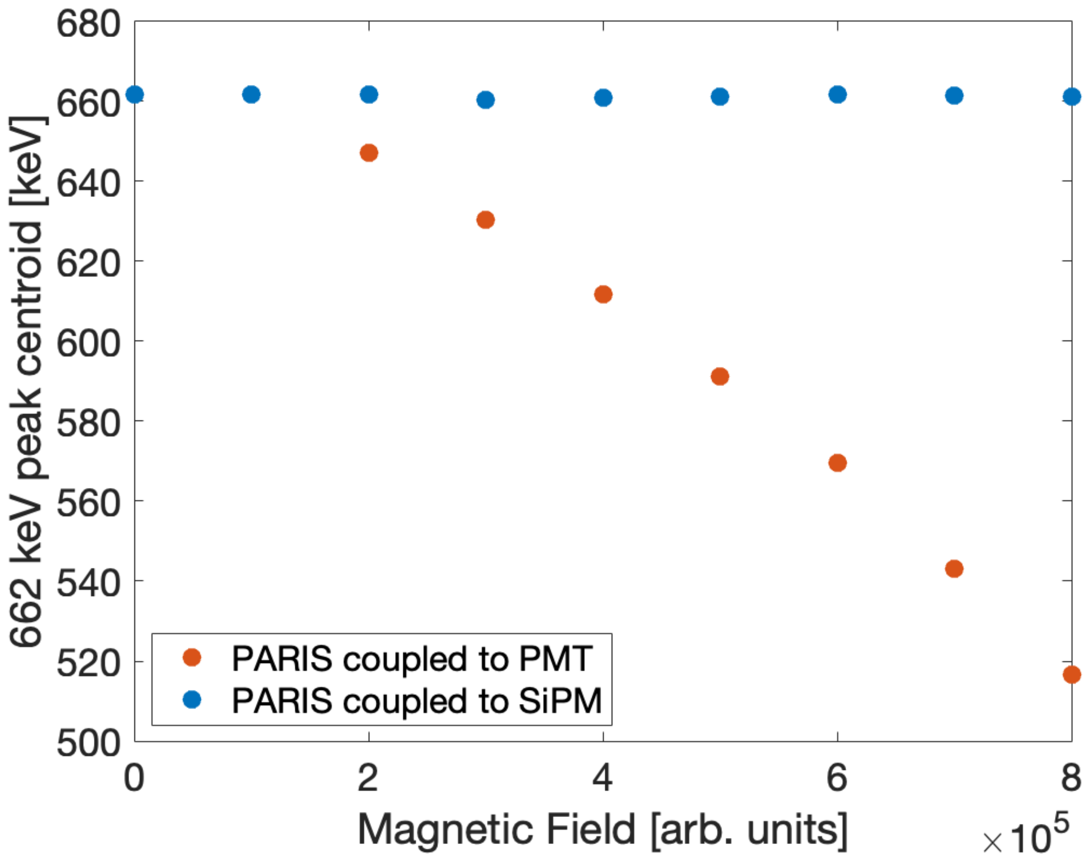
Predictable non-linearity

It depends on the number of **SiPM cells** their **PDE** and the number of photons emitted by the detector.

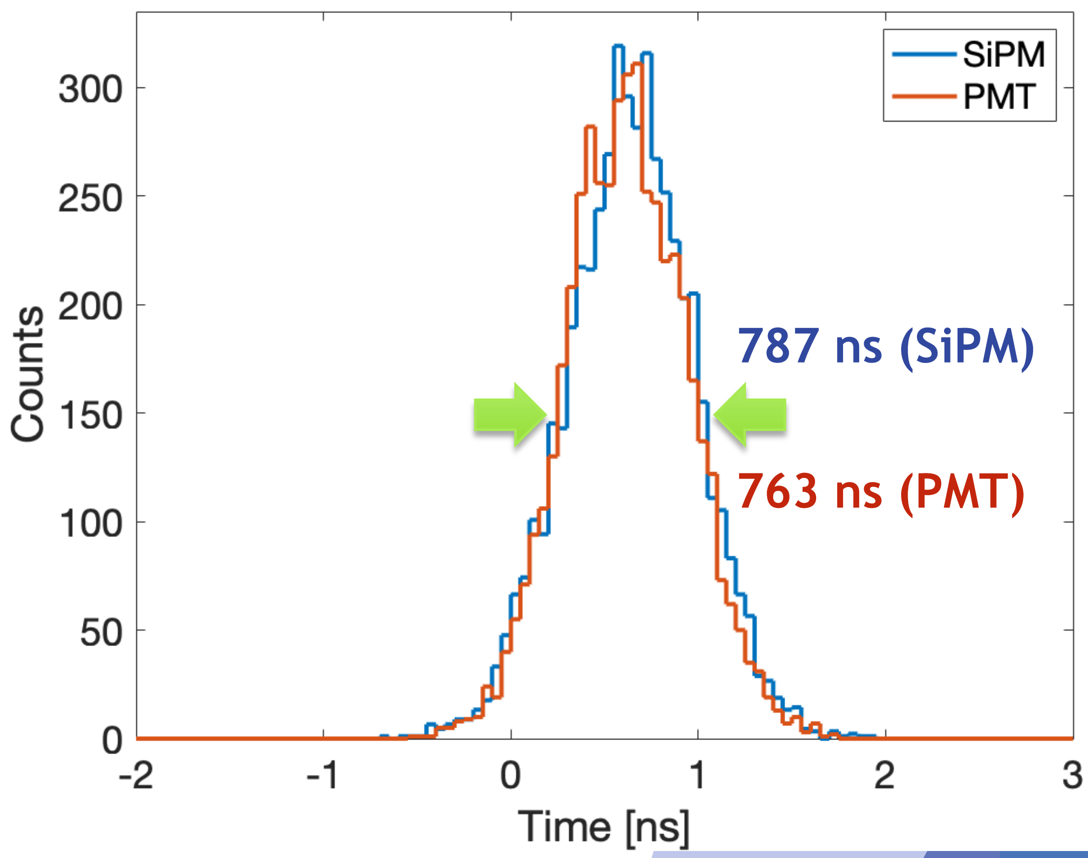


PARIS: SiPMs (II)

SiPMs are not sensible to magnetic field.



Time resolution



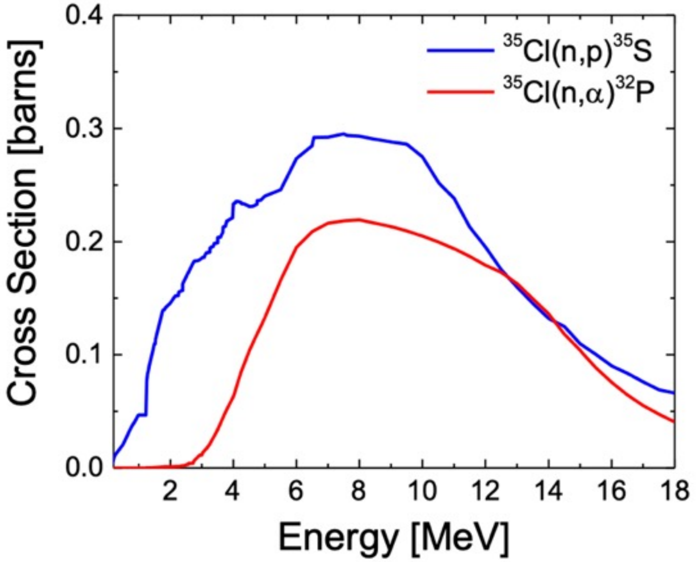
R&D on Scintillators

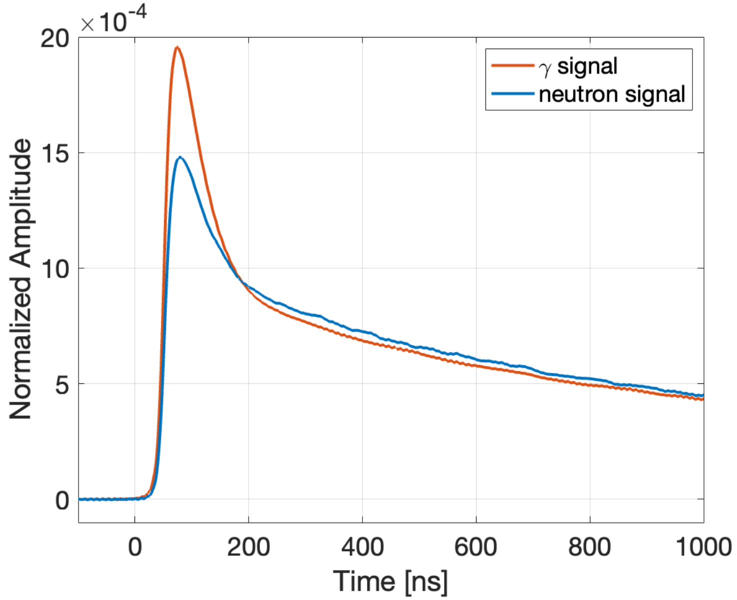
CLYC: fast neutron detection

Why CLYC? Fast neutron detection

Cs_2LiYCl_6:Ce to detect neutron:

- ^{6}Li thermal neutrons ($\sigma \approx 960$ barns)
- ^{35}Cl fast neutrons
  - $^{35}Cl(n,p)35S$
  - $^{35}Cl(n,\alpha)^{32}P$





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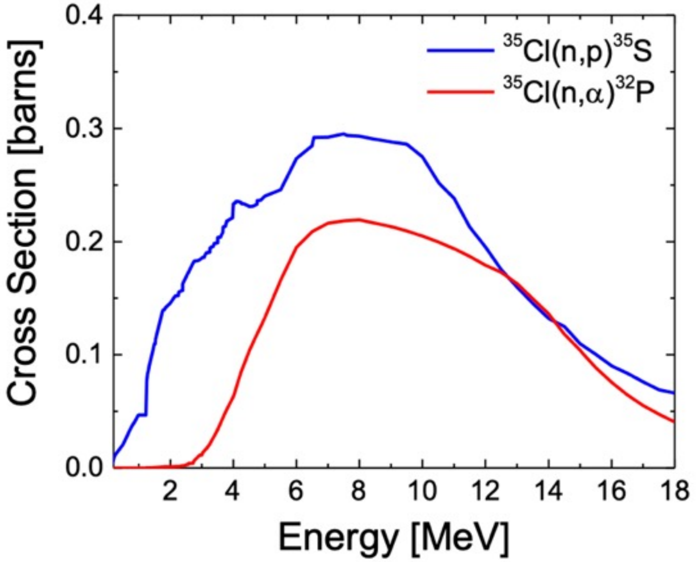

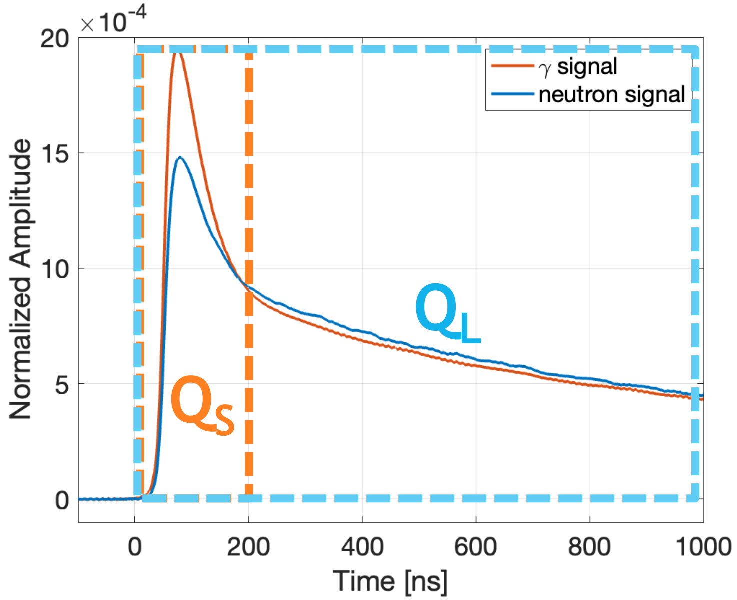

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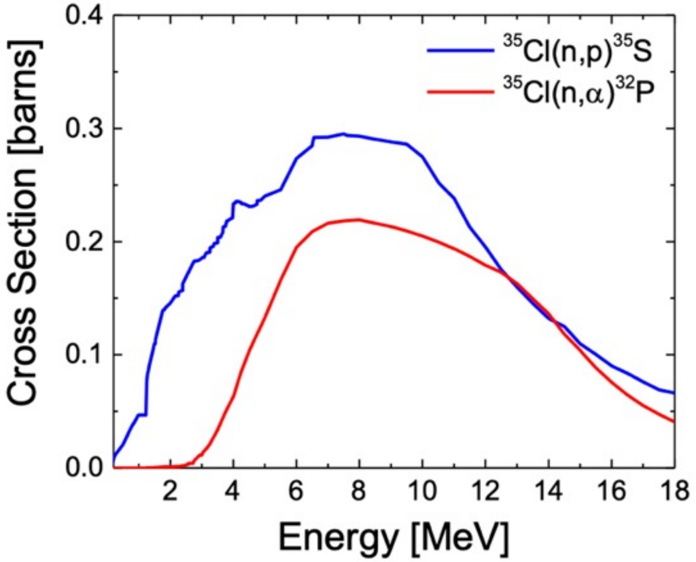

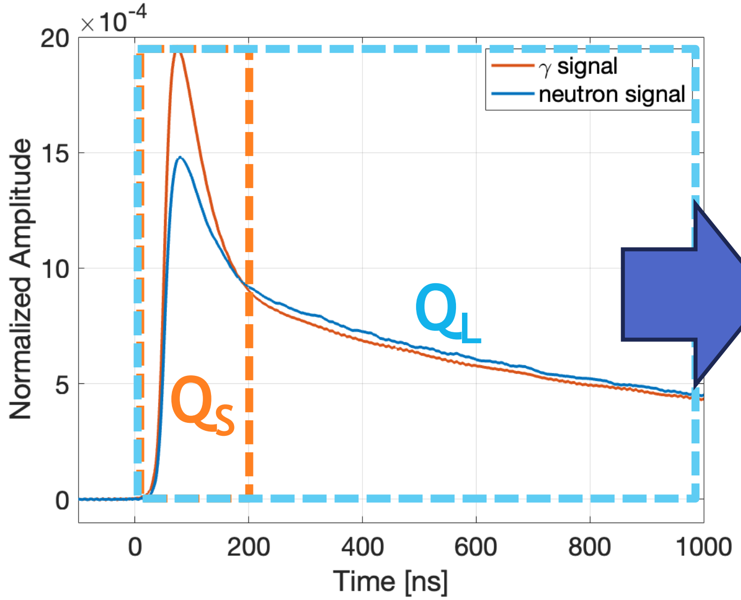

$$PSD\ Ratio = \frac{Q_L - Q_s}{Q_L}$$

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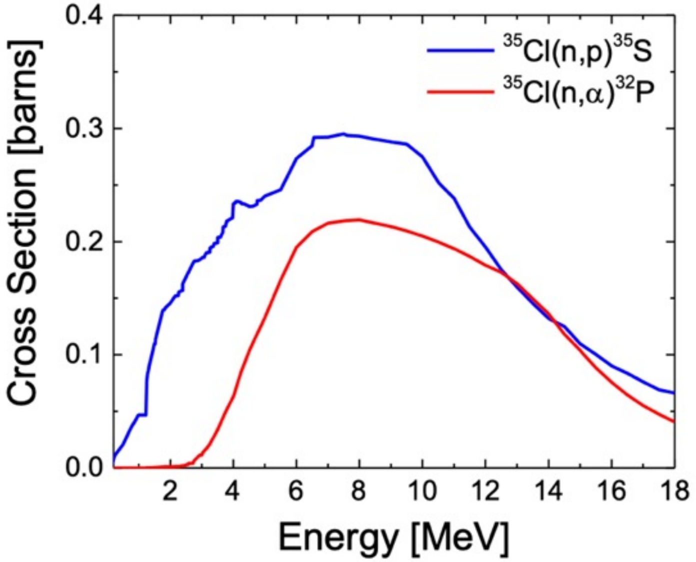

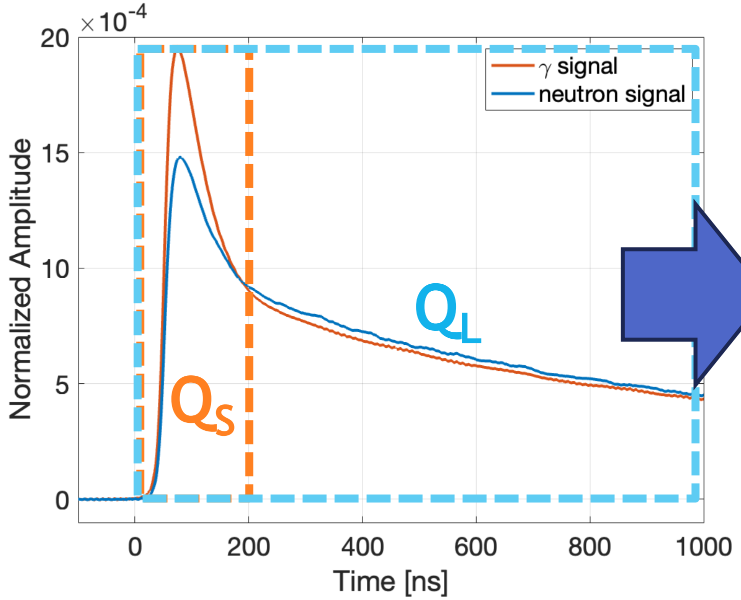

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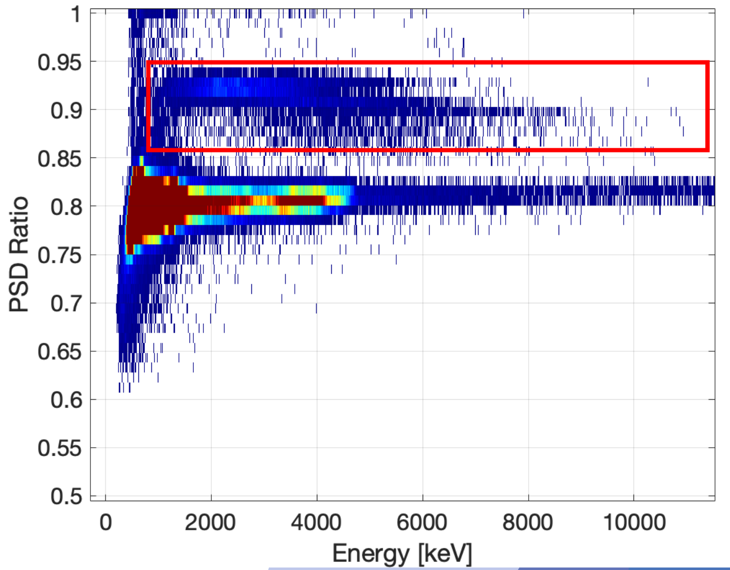
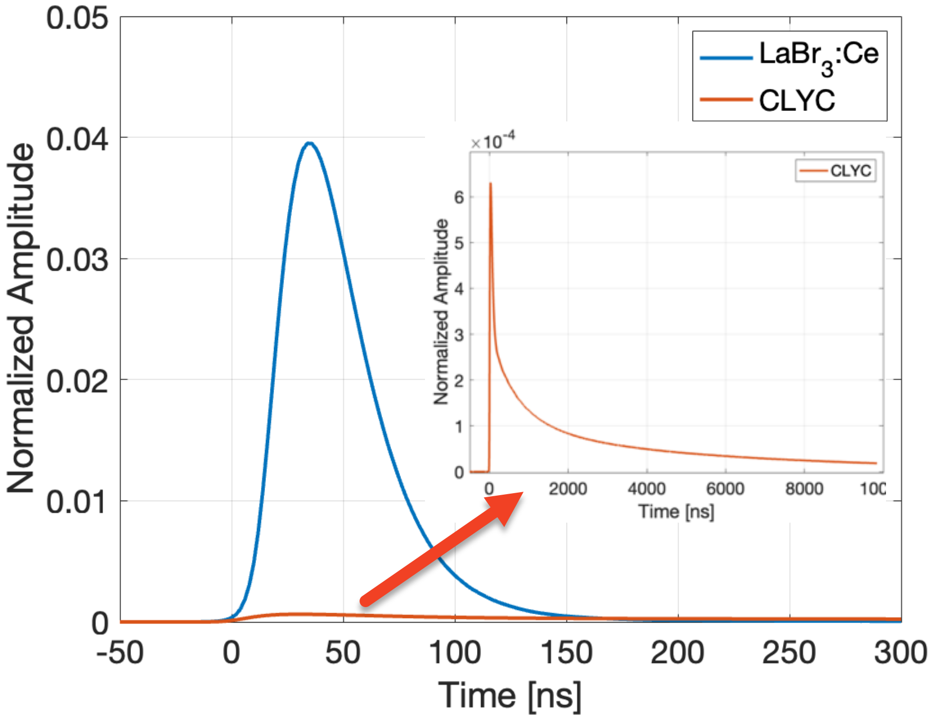


CLYC with SiPM

$LaBr_3$:Ce 63000 ph/MeV – CLYC 20000 ph/MeV

$LaBr_3$:Ce 150 ns – CLYC 10 μs



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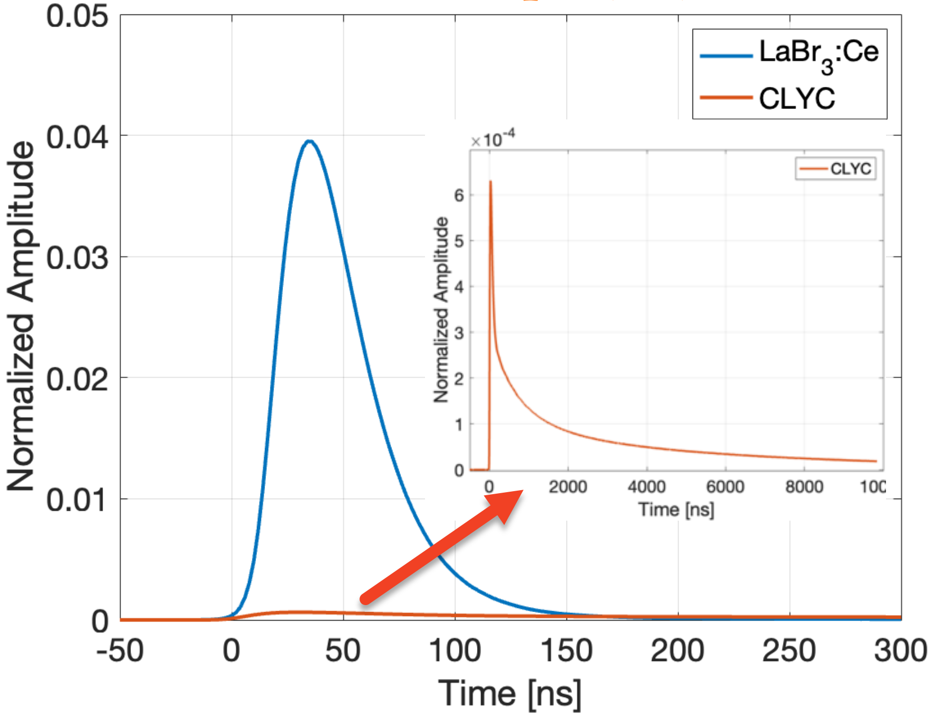
Photon with CLYC @ 1332 keV: **5000 ph**
($LY \times PDE \times FF \times other$?)
DCR in 10 μs at 21°C: **50 ph (1%)**



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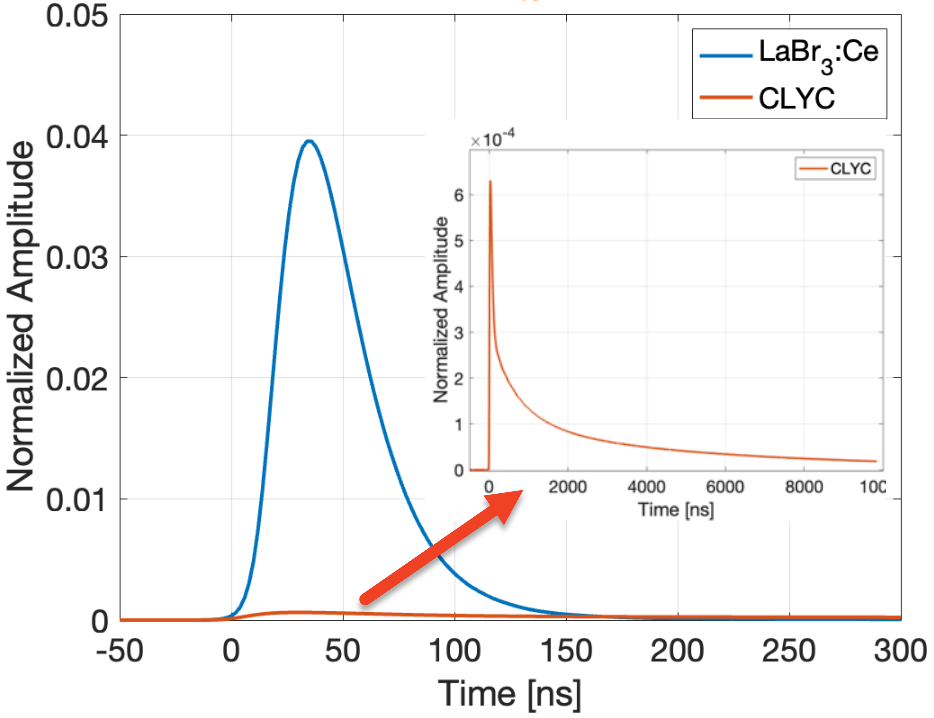
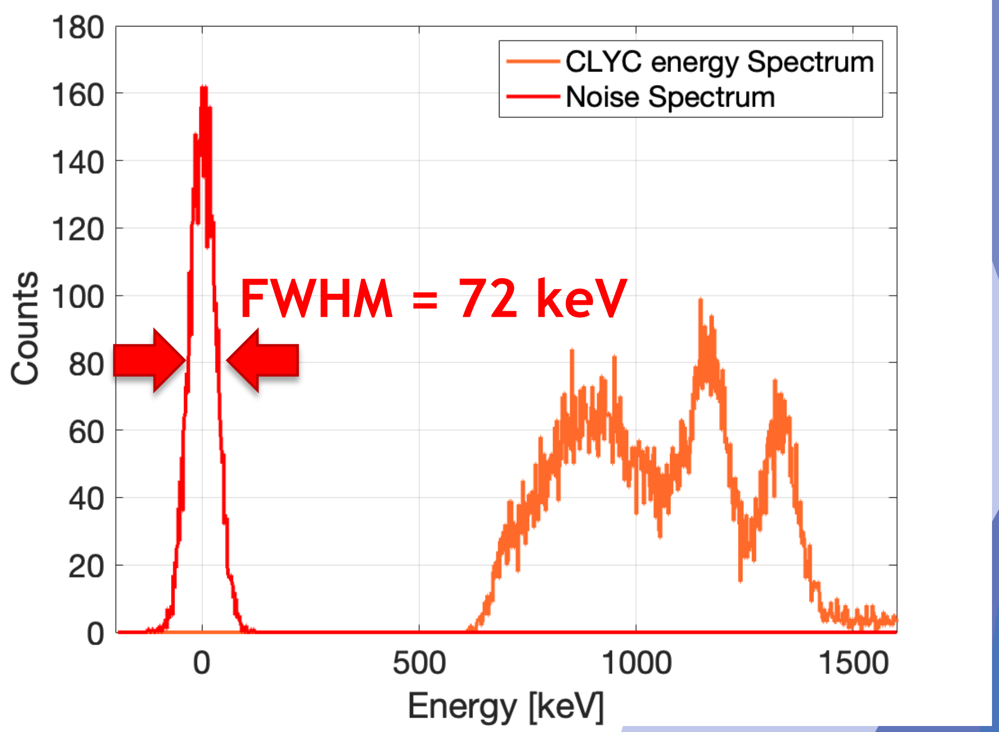


FHWM @ 662 = 30 keV (4.5%)

FWHM @ 1332 keV = 43 keV

Measured **Noise FWHM = 72 keV**



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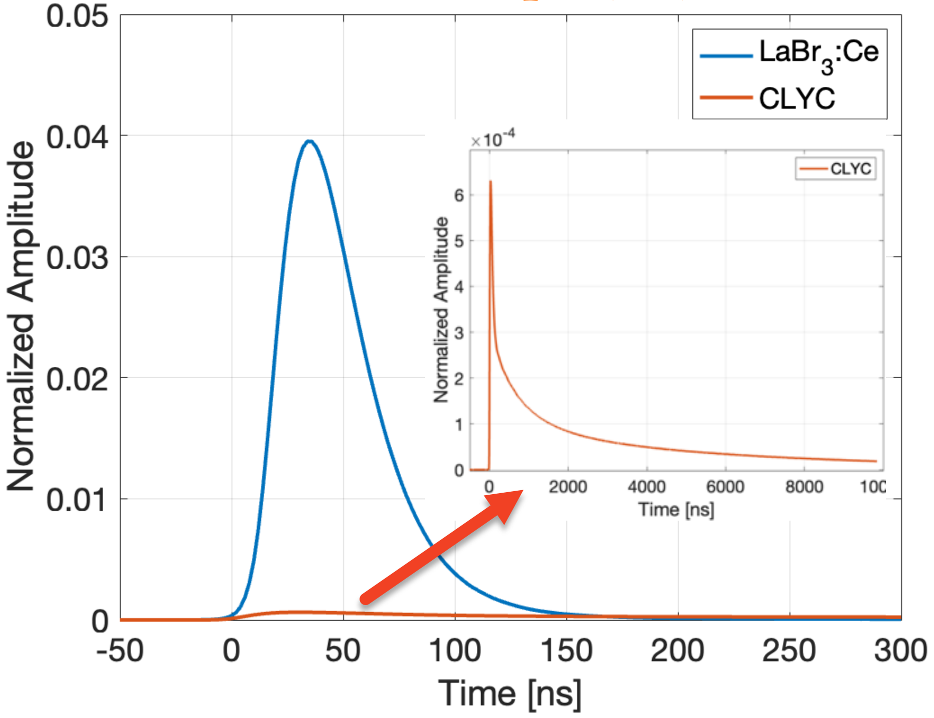

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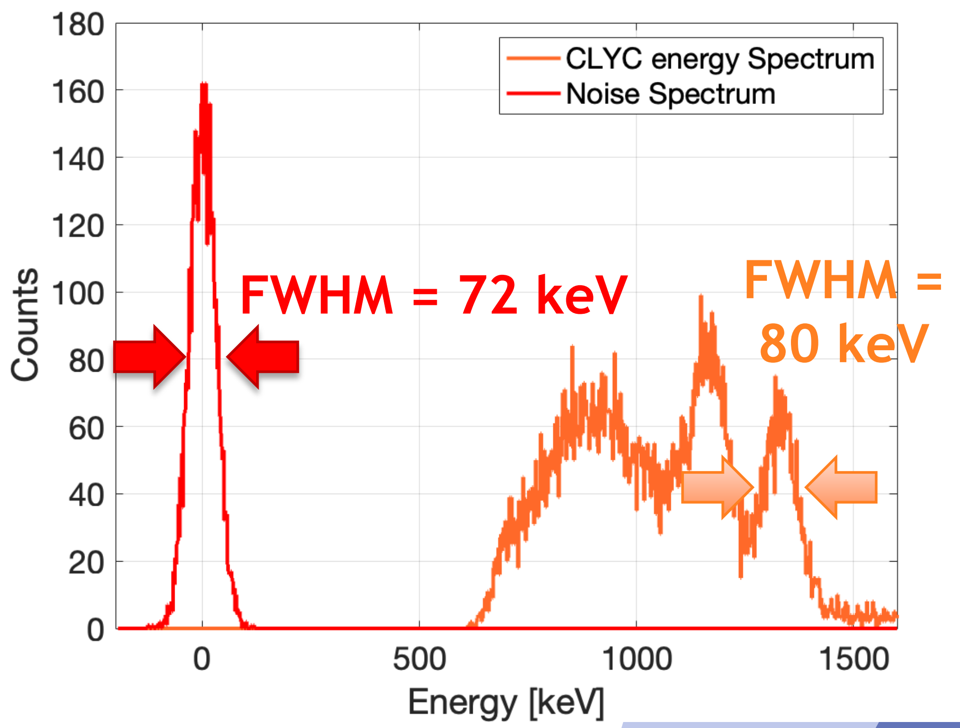
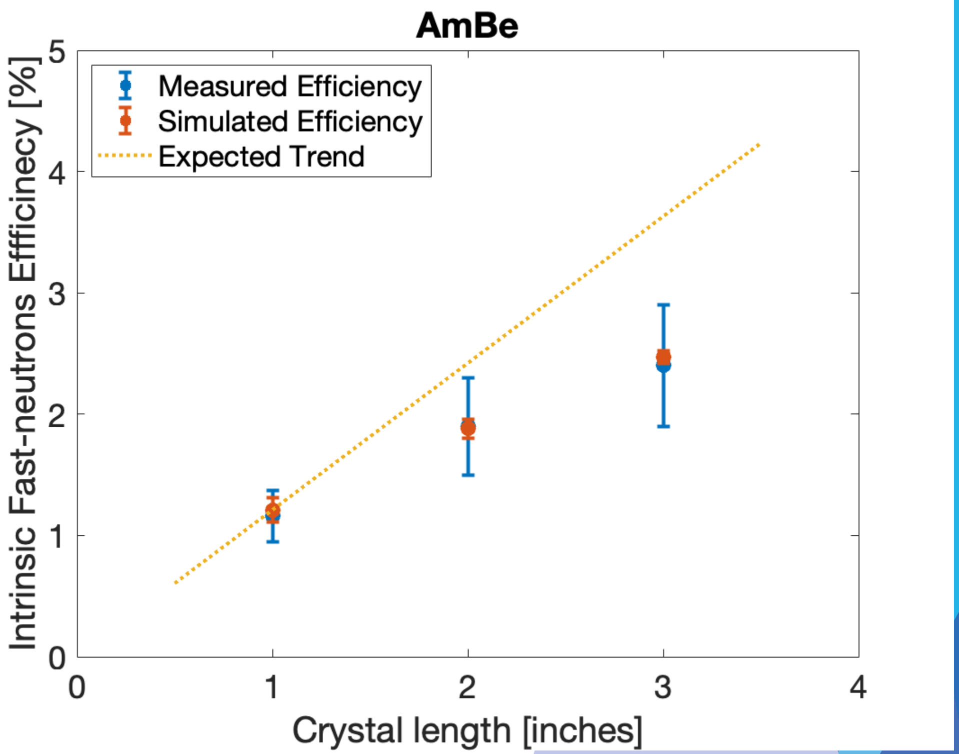
Measured Noise FWHM = 72 keV

$$FWHM_{Expected} = \sqrt{FWHM_{noise}^2 + FWHM_{1332}^2} = 84 \text{ keV}$$



CLYC: efficinecy

Detector	Detected neutrons	Measured Ratio	Simulated Ratio
1” x 1”	0.19 ± 0.01 n/s	1.00 ± 0.07	1.00
2” x 2”	1.21 ± 0.01 n/s	6.53 ± 0.60	6.71
3” x 3”	3.46 ± 0.03 n/s	18.78 ± 0.36	19.43



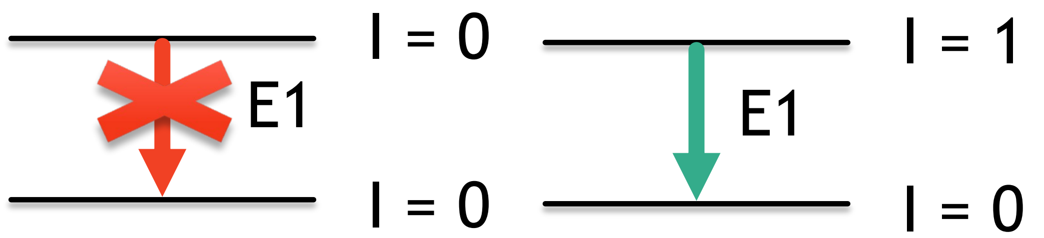
The fast-neutron efficiency does not scale with volume/thinckness.

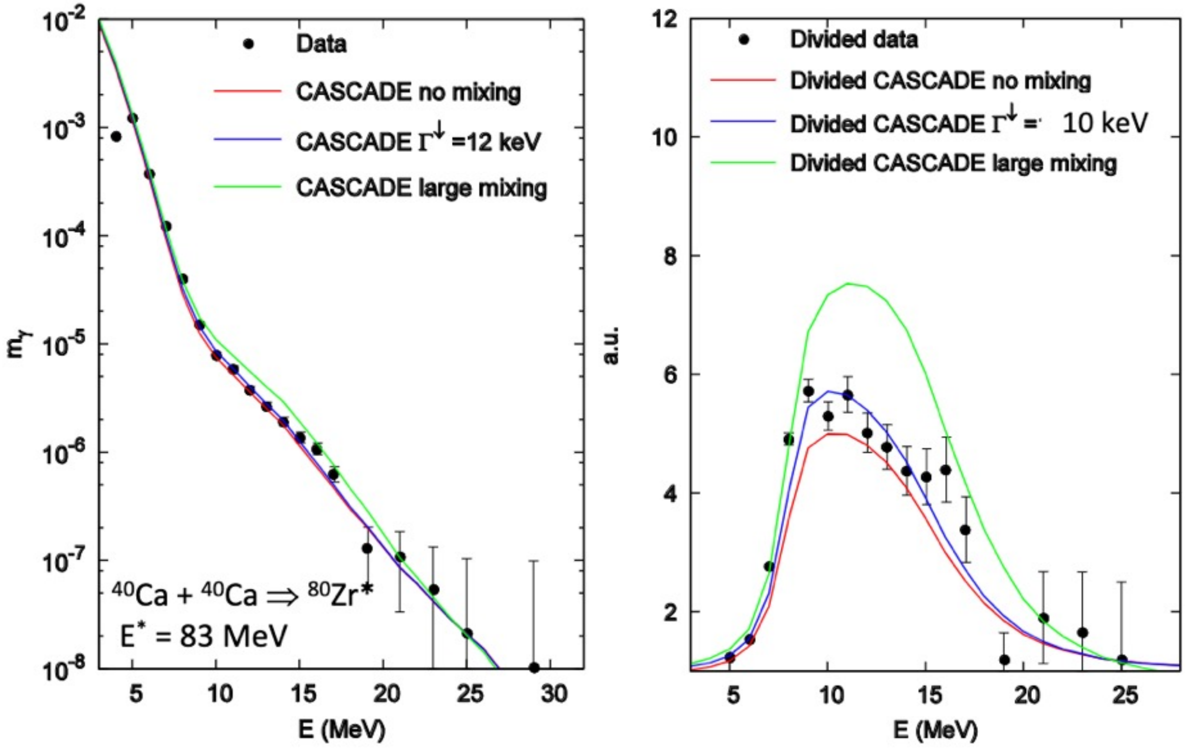
Measurements of collective motions in nuclei with scintillators

Isospin mixing in ^{72}Kr

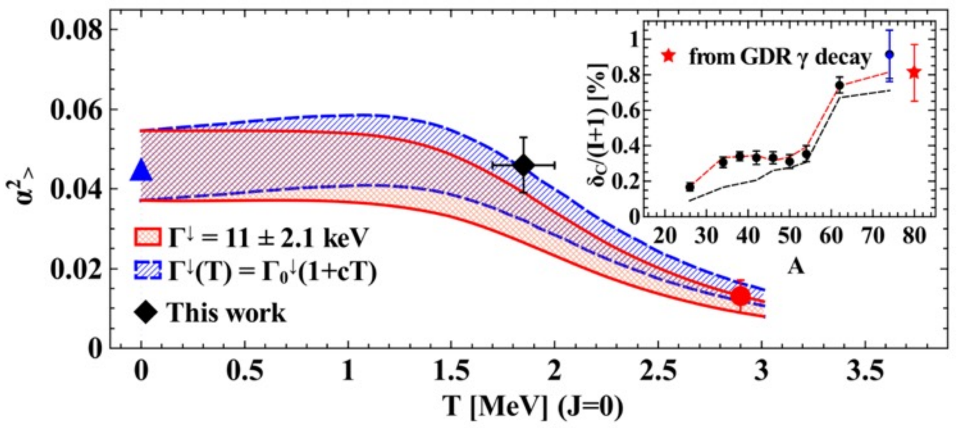
Isospin Mixing

In N=Z nuclei with isospin equal zero E1 γ-ray emission is forbidden by selection rules. The isospin symmetry is broken by Coulomb force.





A. Corsi et al., PRC 84, 041304(R) (2011)



S. Ceruti et al., PRL 115, 222502 (2015)

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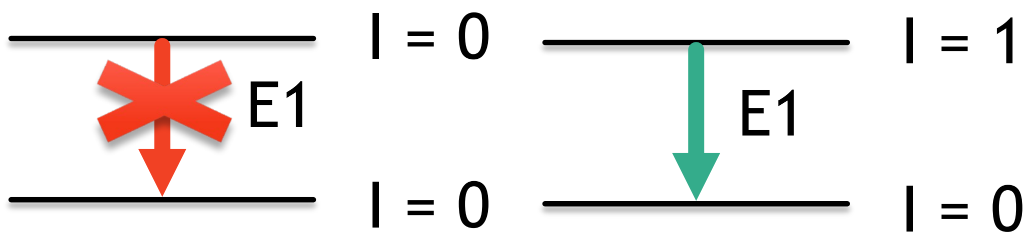

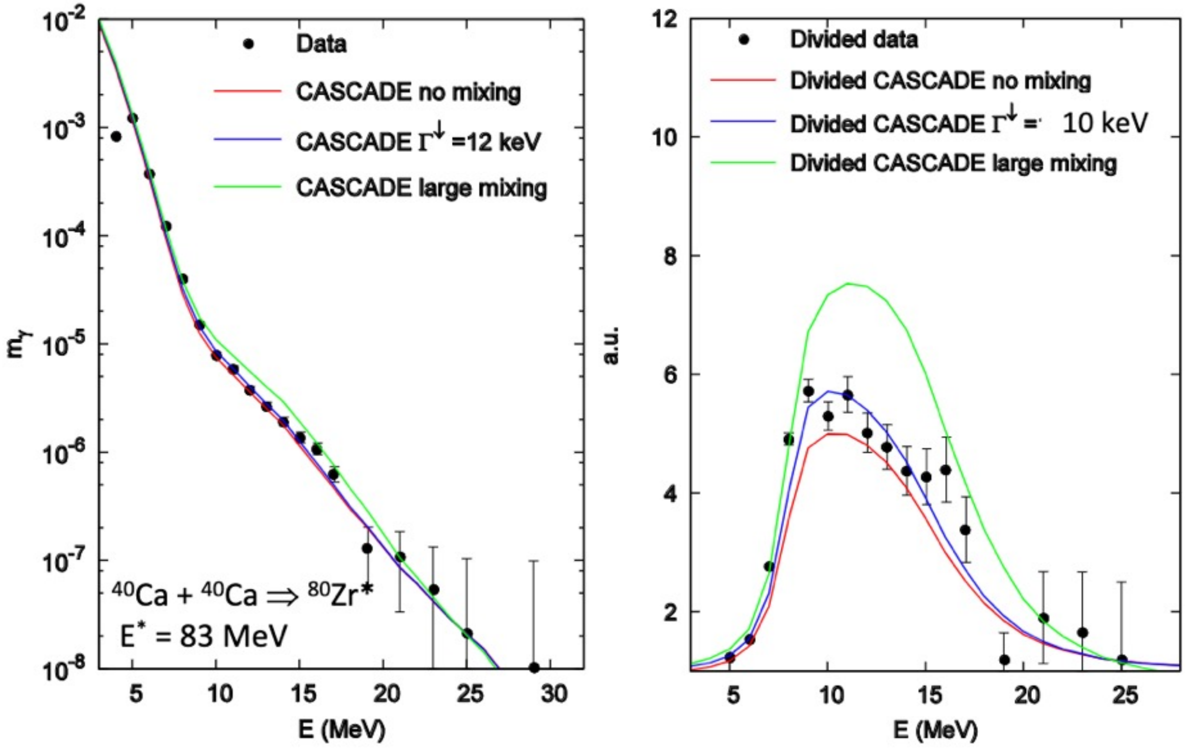

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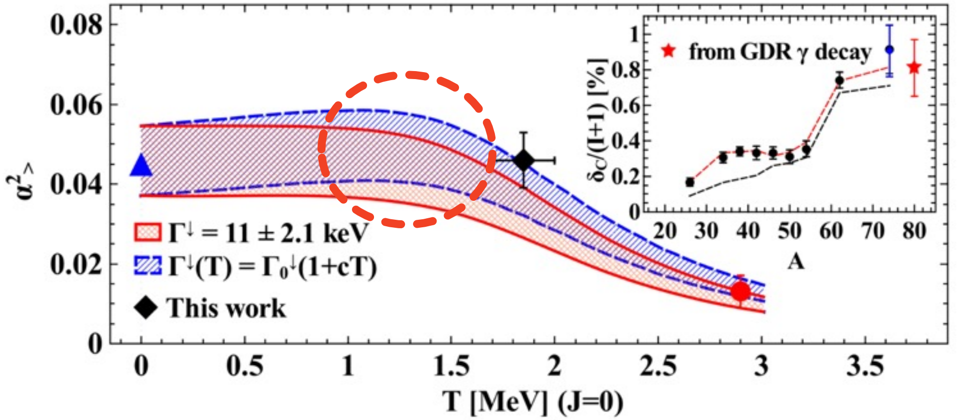

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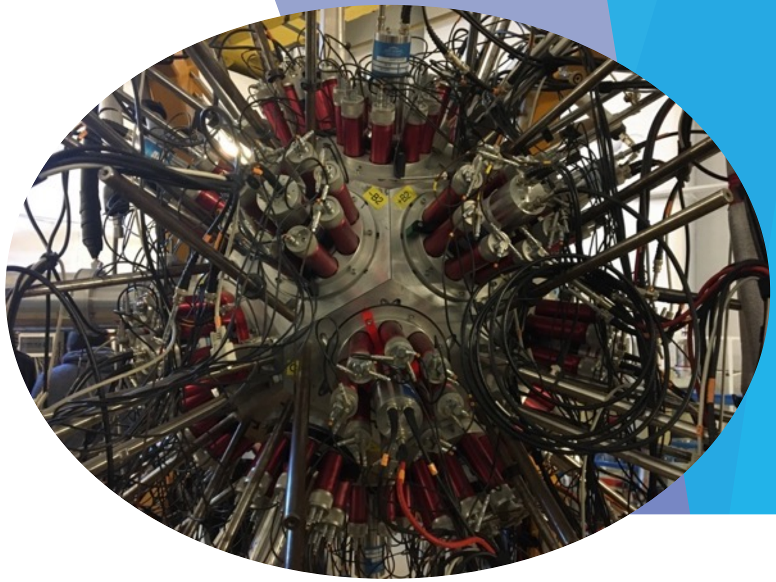
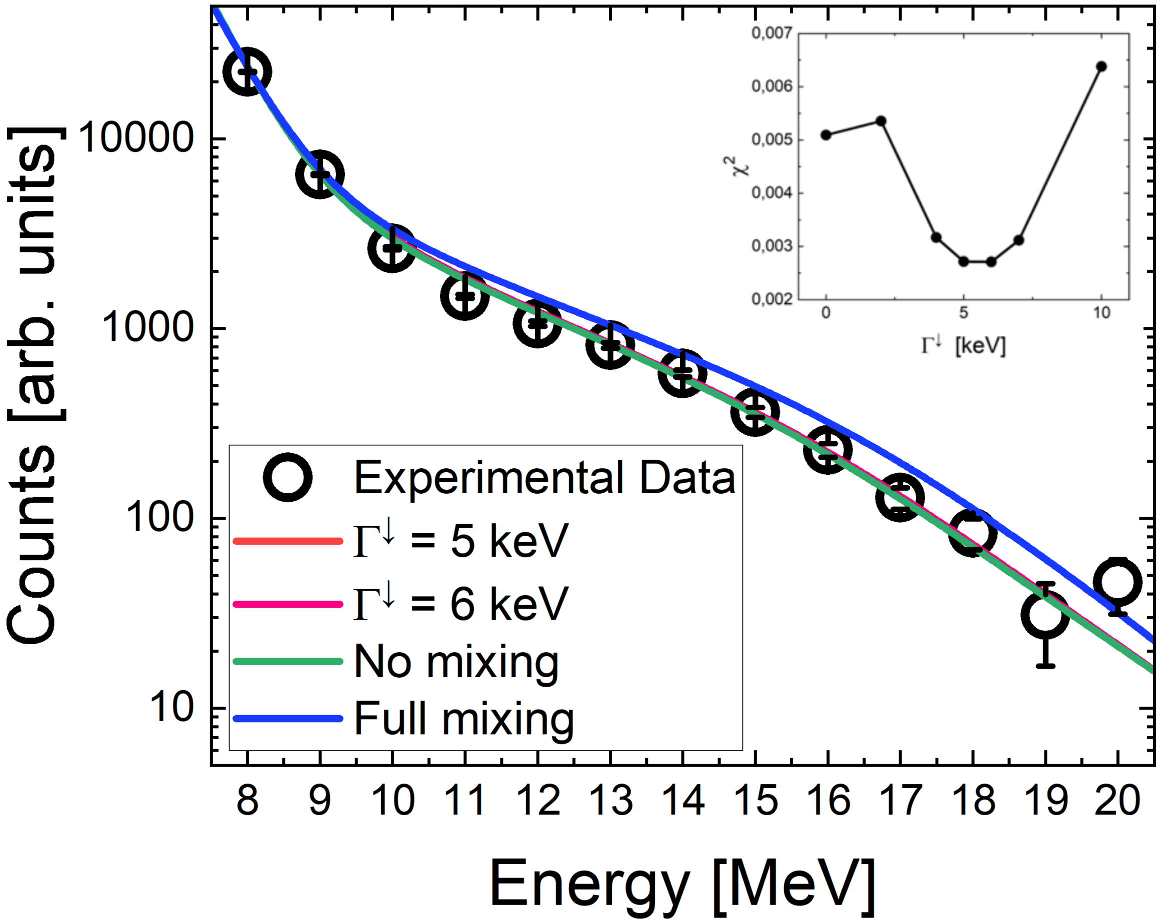
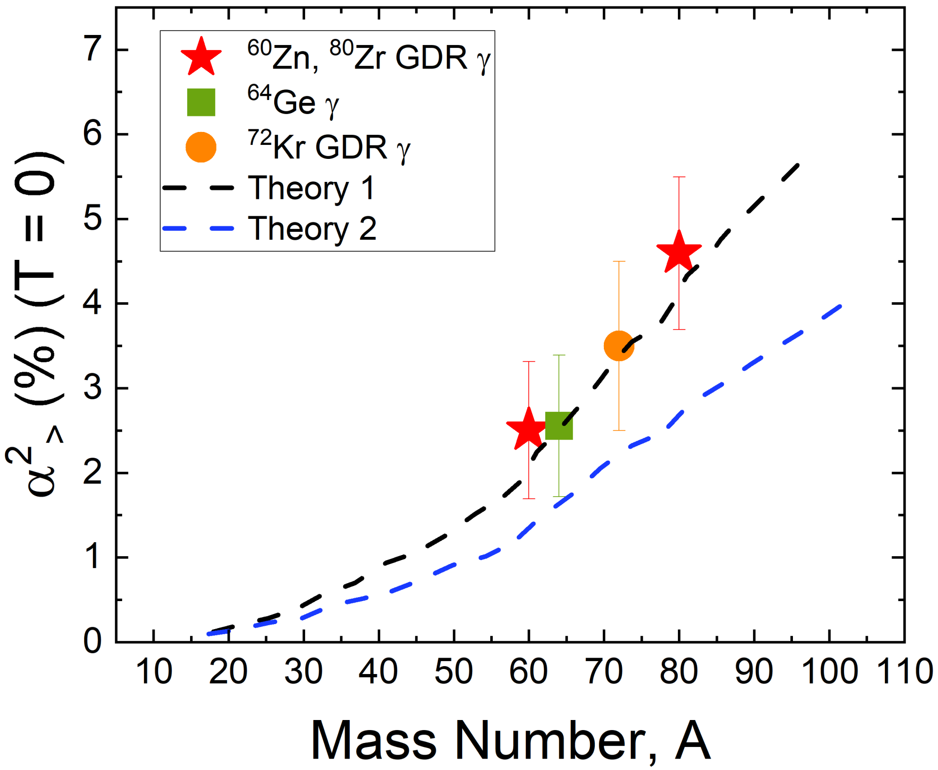
Isospin mixing in ^{72}Kr at T=1.3 MeV

Bucharest: ELIGANT setup







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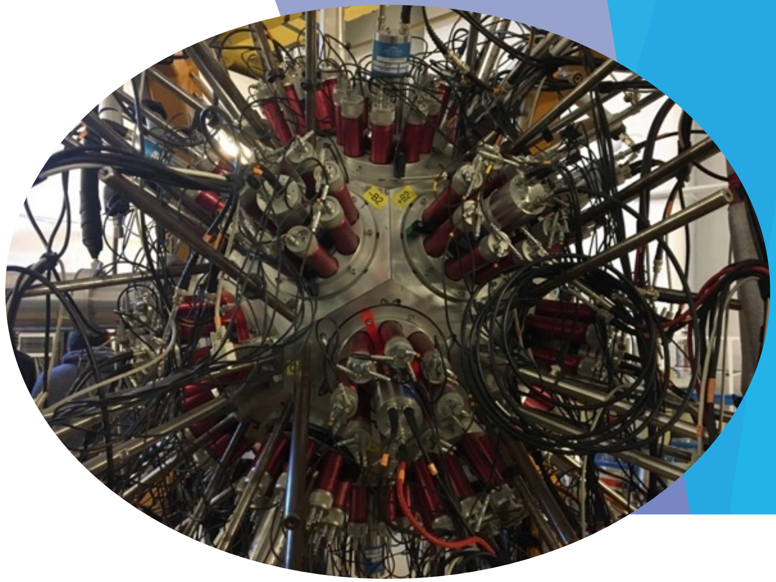
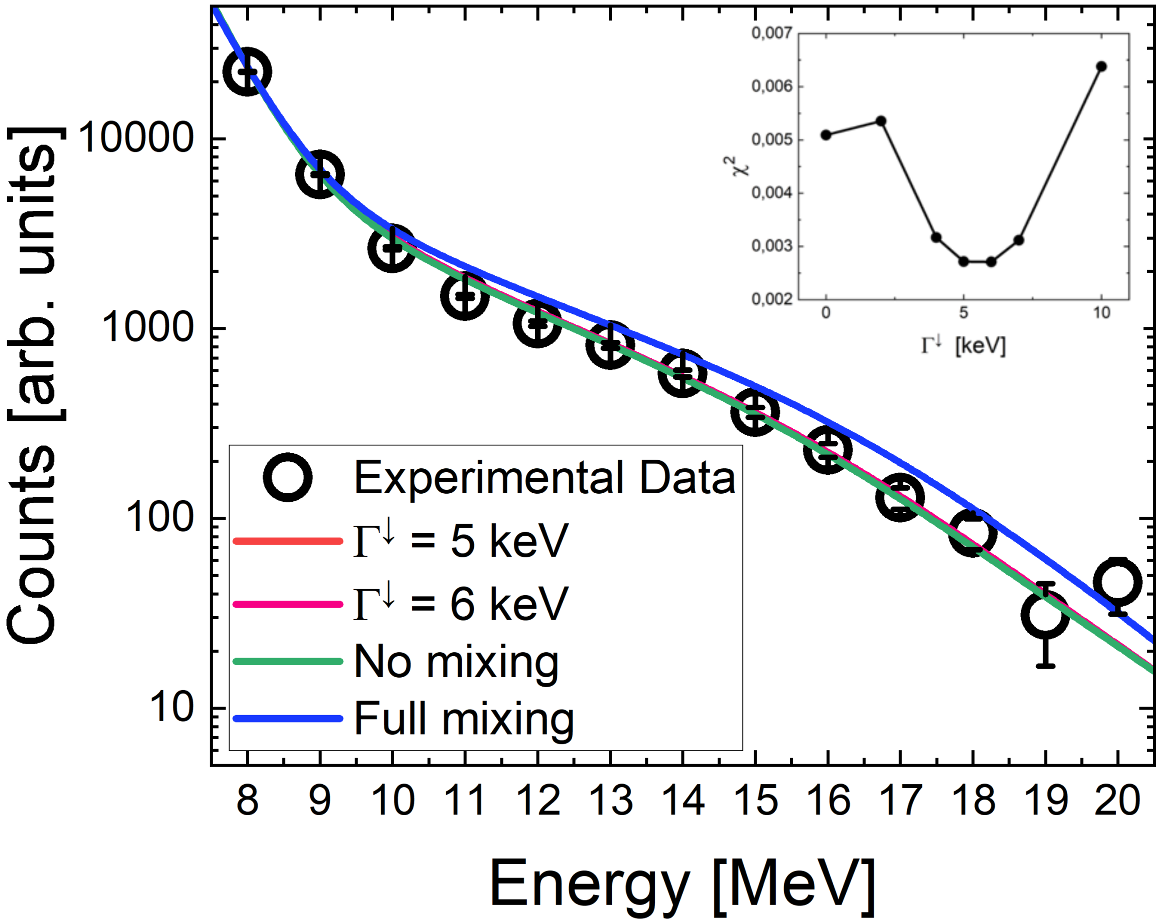
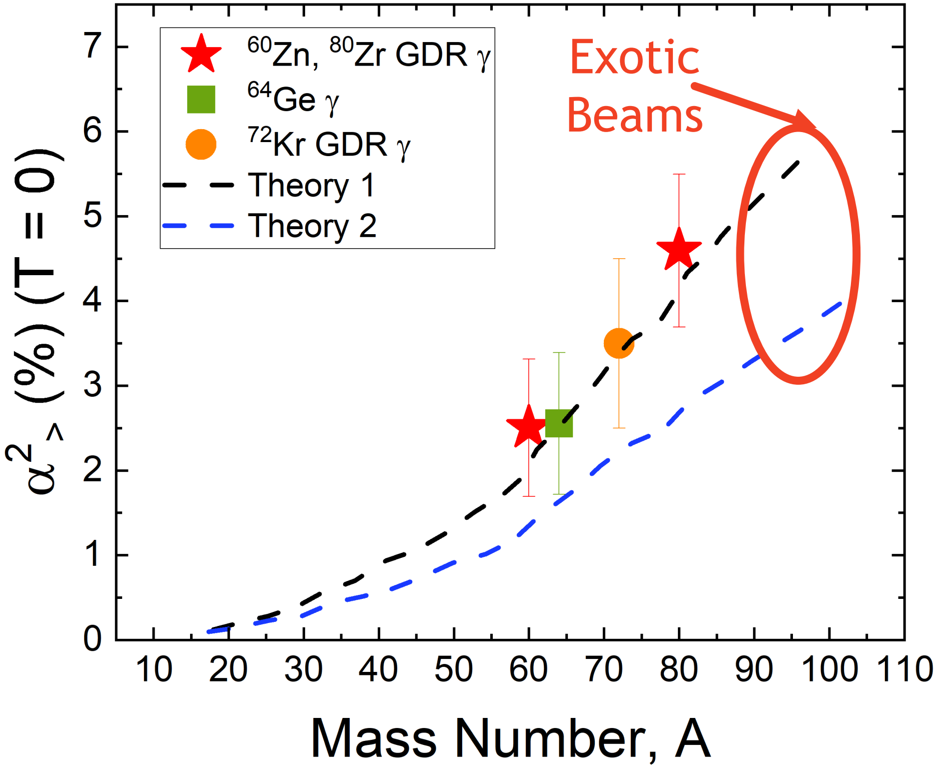
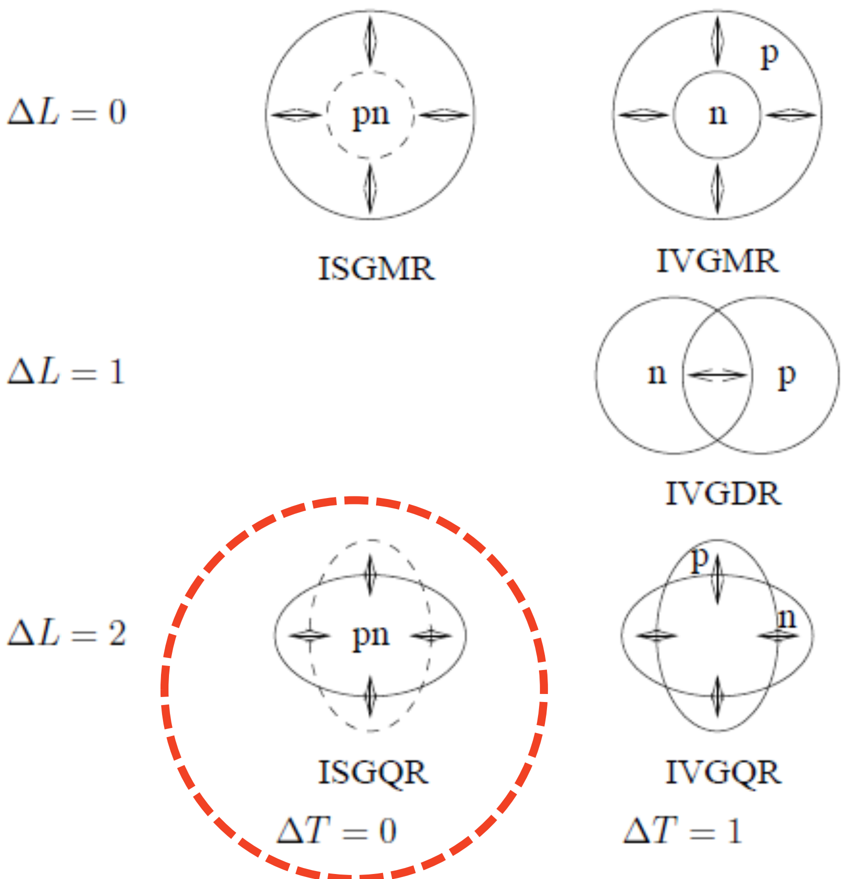




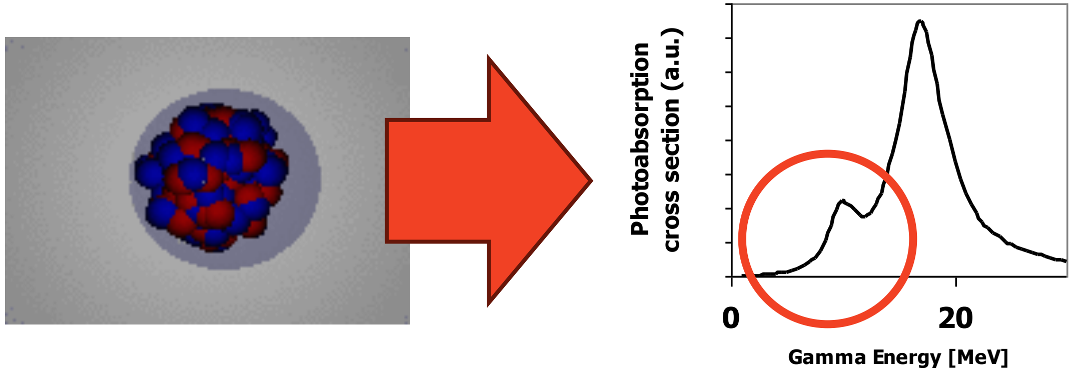


PDR in A~60 and ISGQR in A=120 mass regions (I)

Collective response of nuclei of external excitation



Collective oscillation of neutron skin against the core



Why Pygmy?

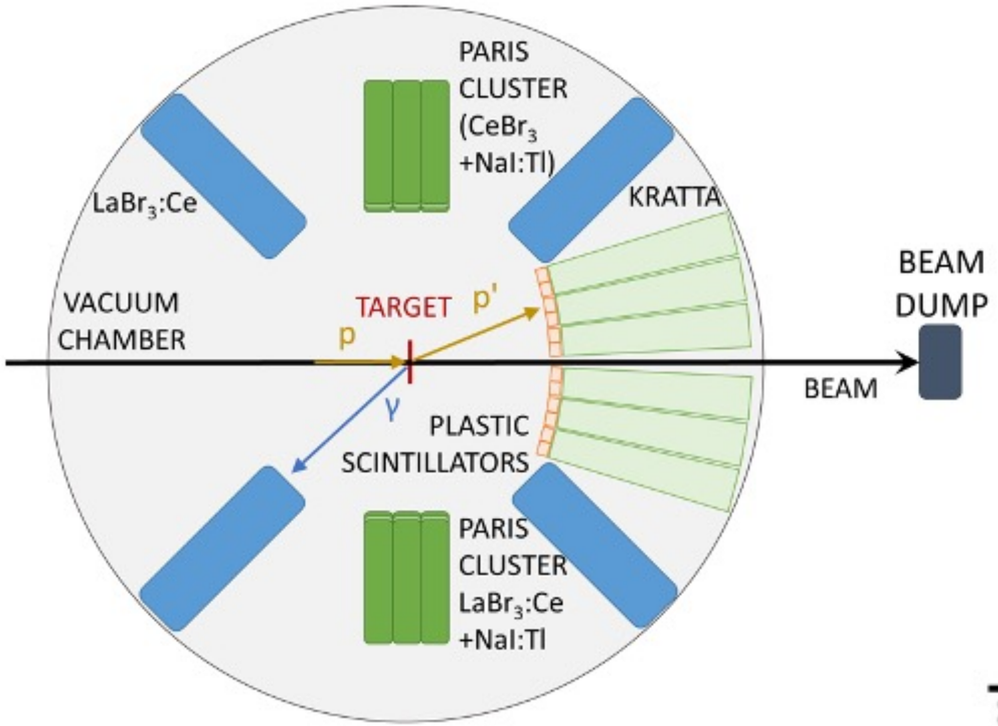
- impact on the **r-process nucleosynthesis;**
- determination of **nuclear symmetry energy;**
- **neutron skin thickness** determination.

Measurements of collective motions in nuclei with scintillators

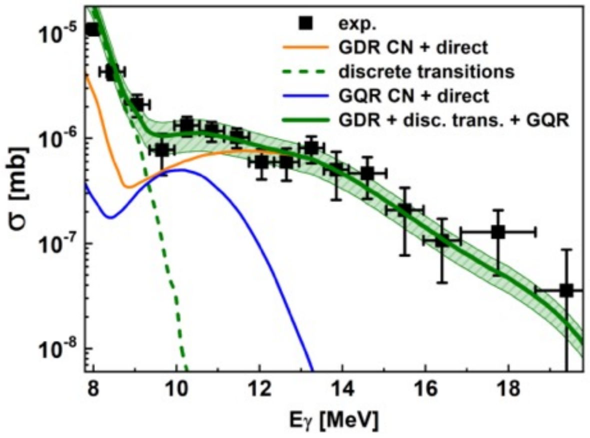
ISGQR in ^{120}Sn

PDR in ^{58}Ni and ^{62}Ni

PDR in A~60 and ISGQR in A=120 mass regions (II)



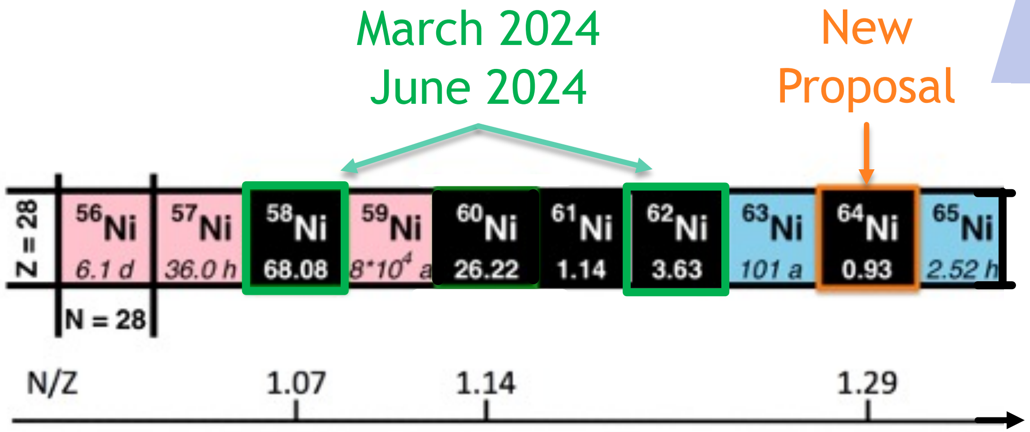
Iso Scalar Giant Quadrupole Resonance at A = 120



γ decay to the ground state from above the $E_{n,th}$ in the ^{208}Pb(p, p' γ) reaction at 85 MeV*

*B. Wasilewska et al. PRC 105, 014310 (2022)

Pygmy Dipole Resonance in A~60 region



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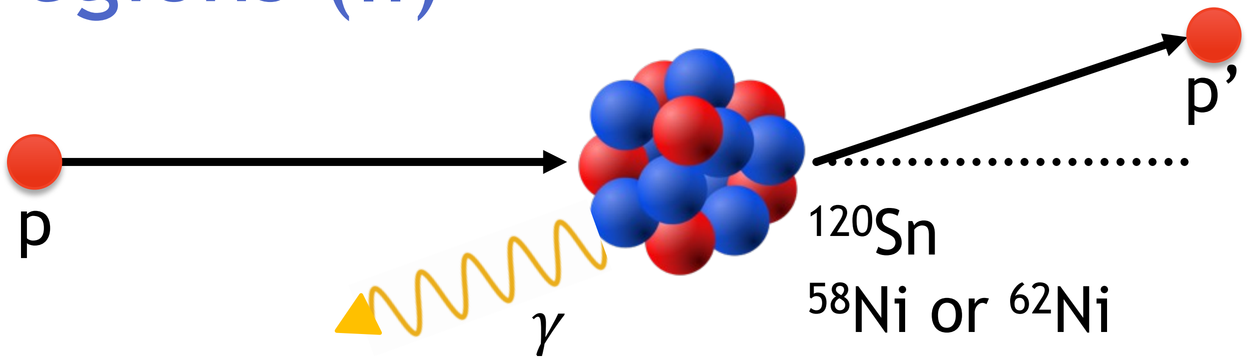
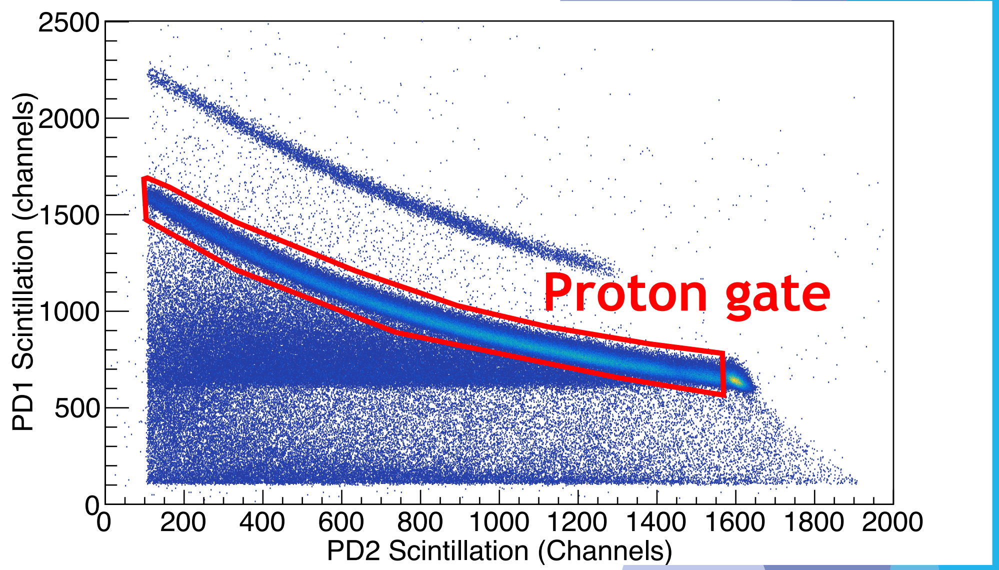
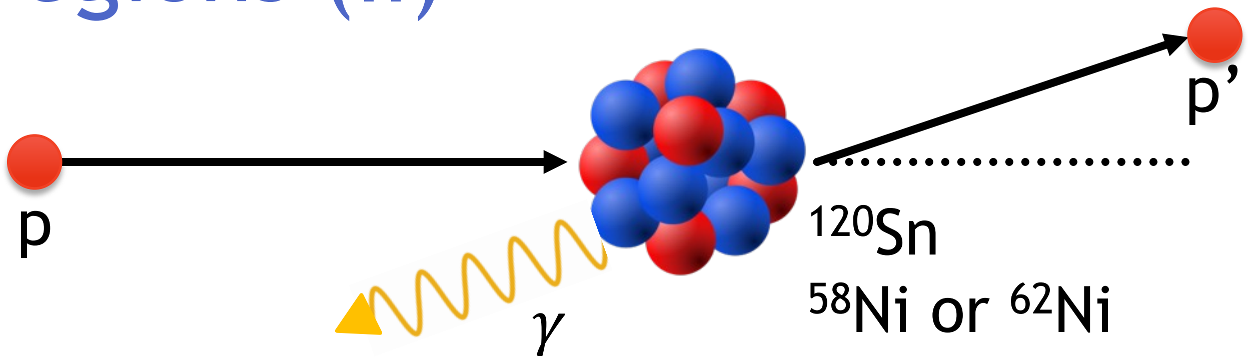
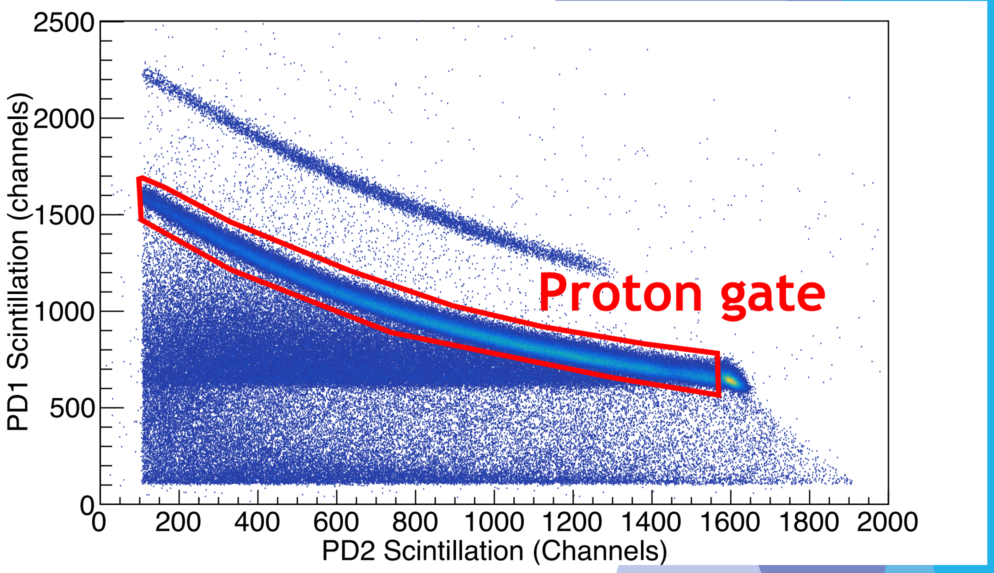
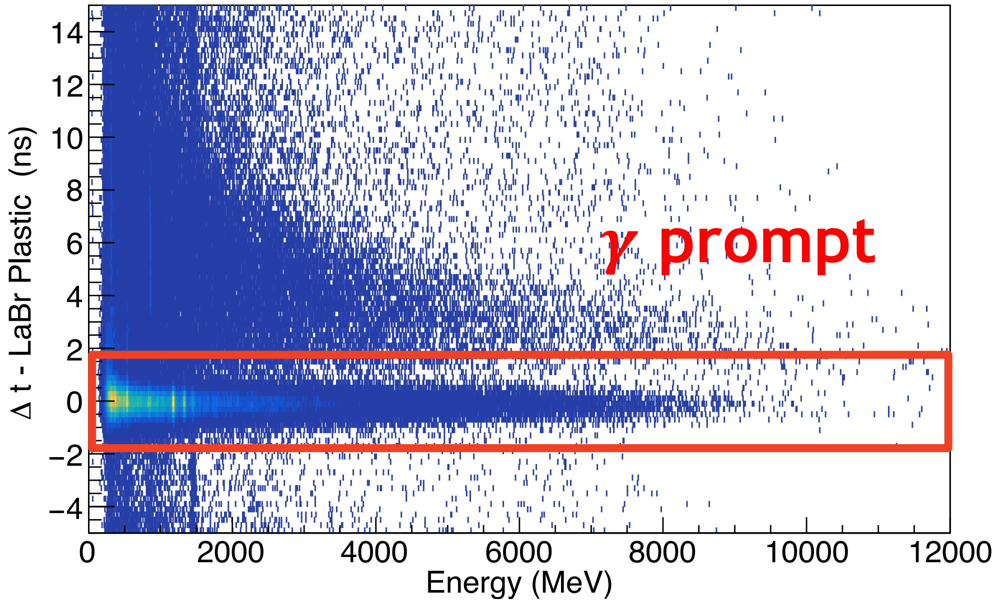




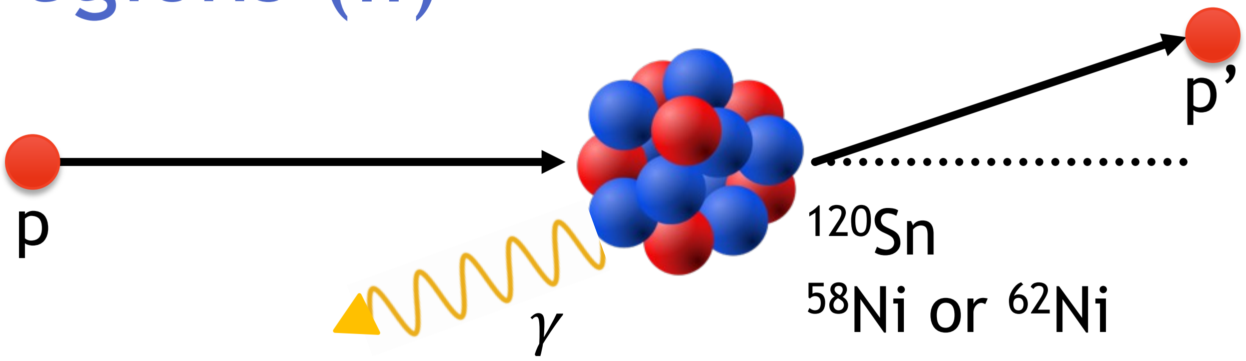
PDR in A~60 and ISGQR in A=120 mass regions (II)

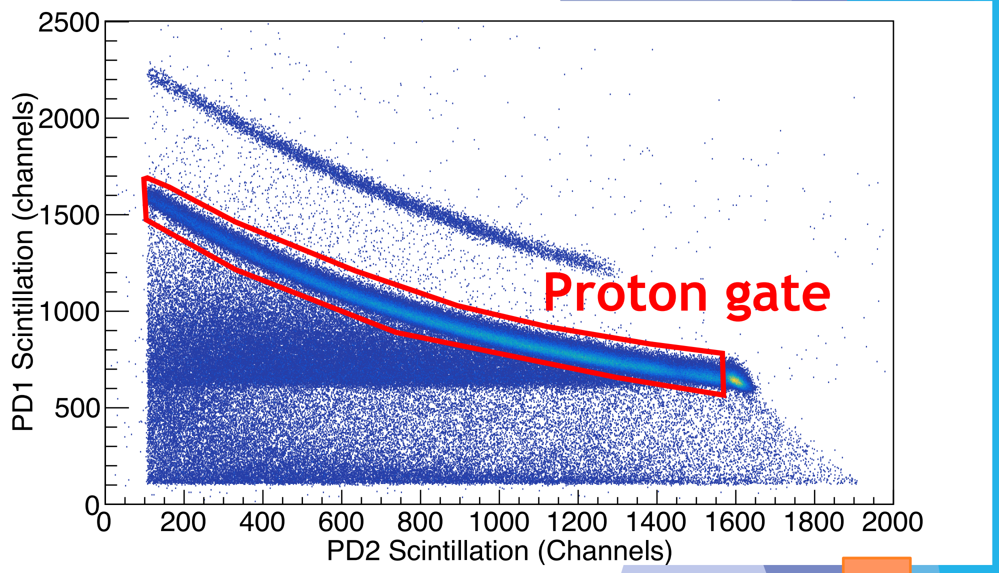


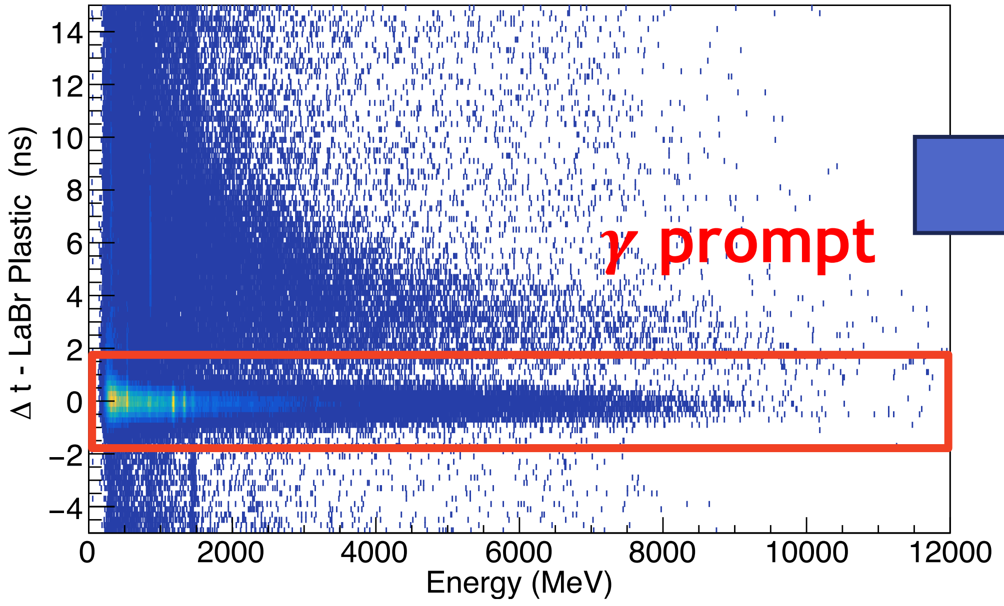


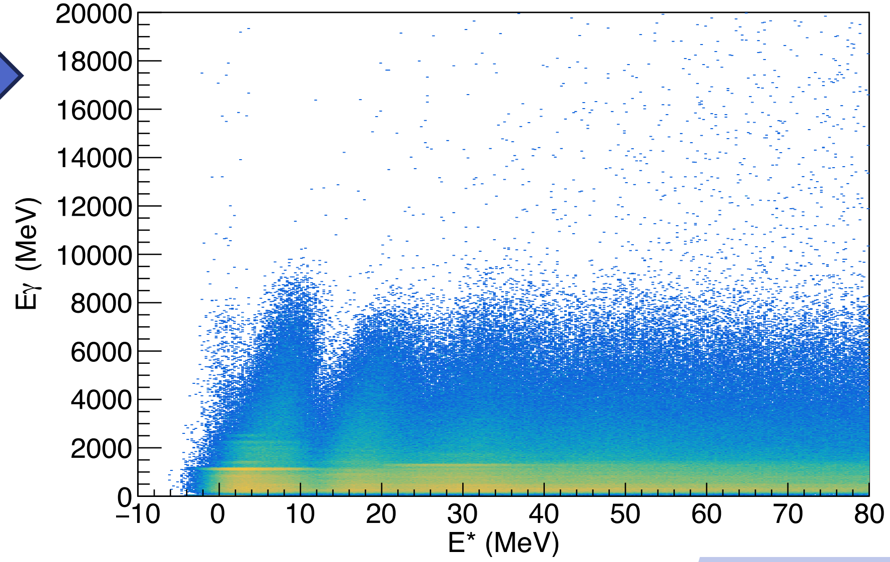


PDR in A~60 and ISGQR in A=120 mass regions (II)

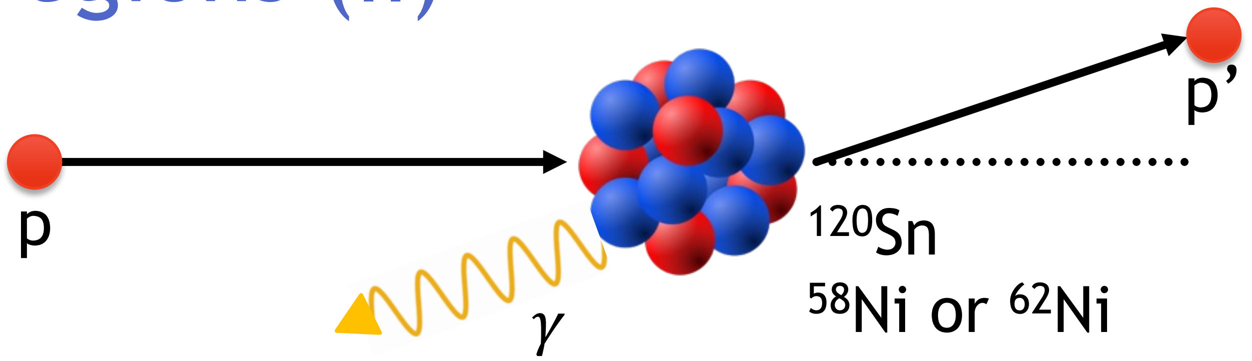


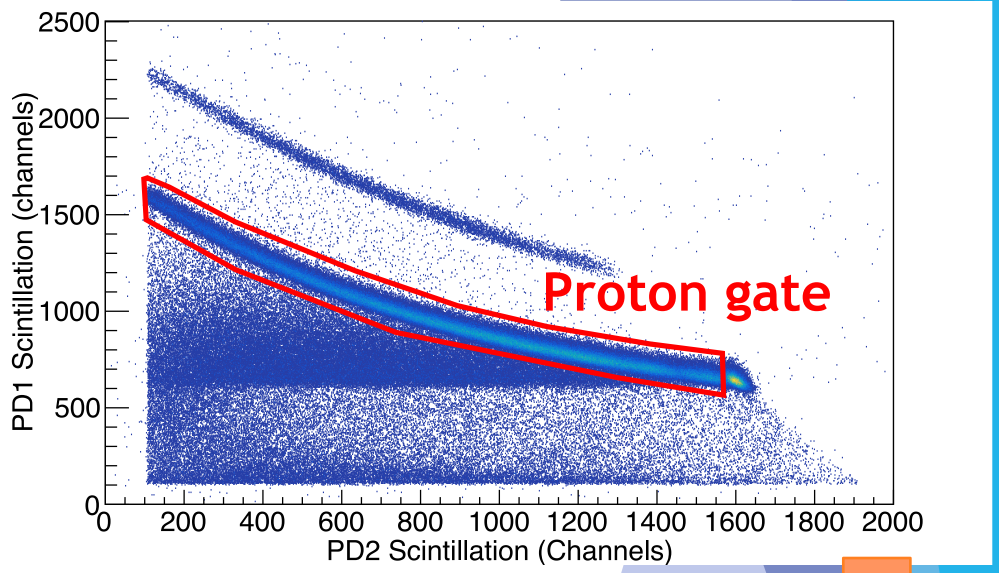


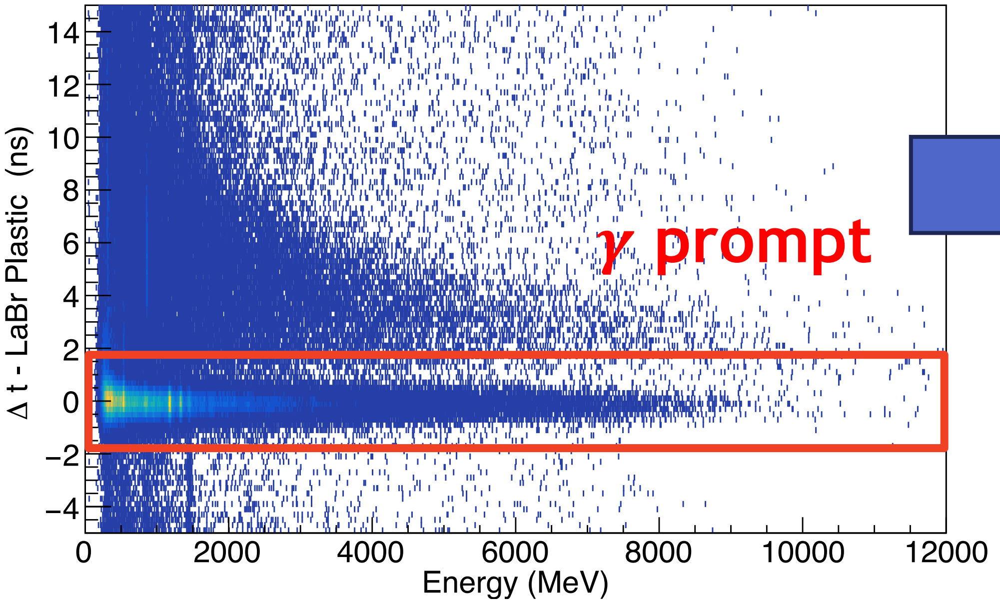


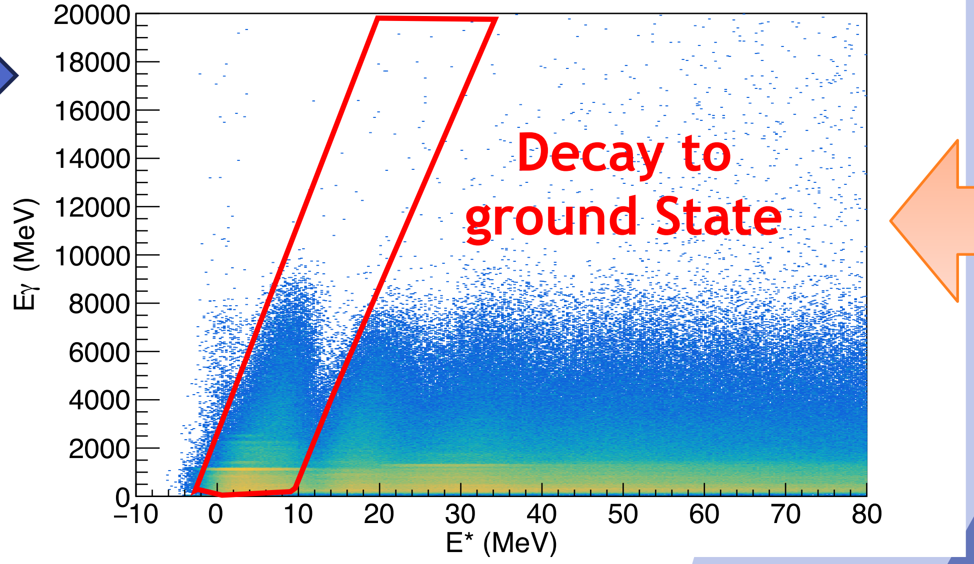


PDR in A~60 and ISGQR in A=120 mass regions (II)

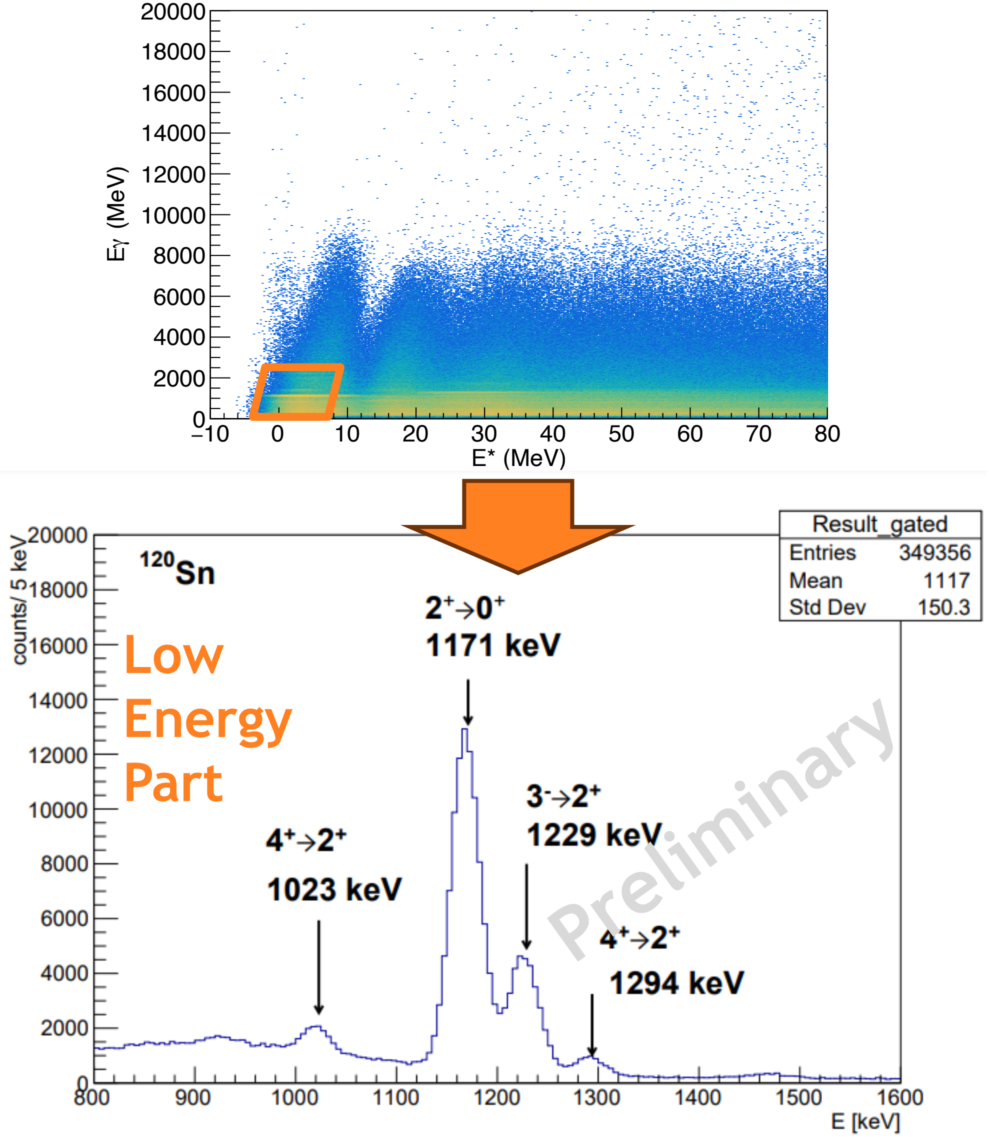




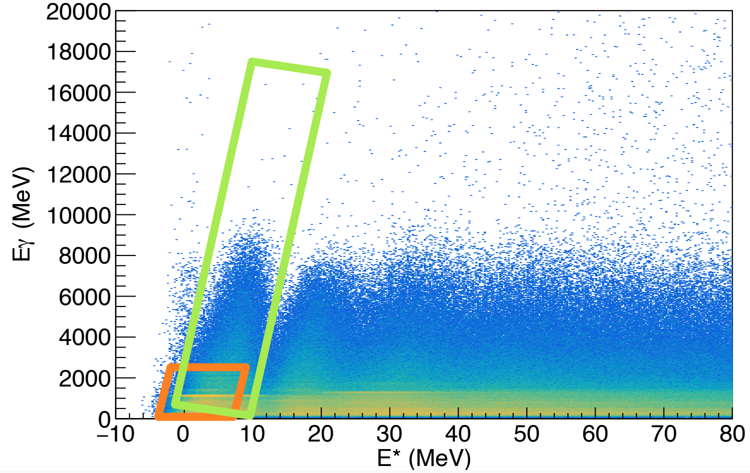


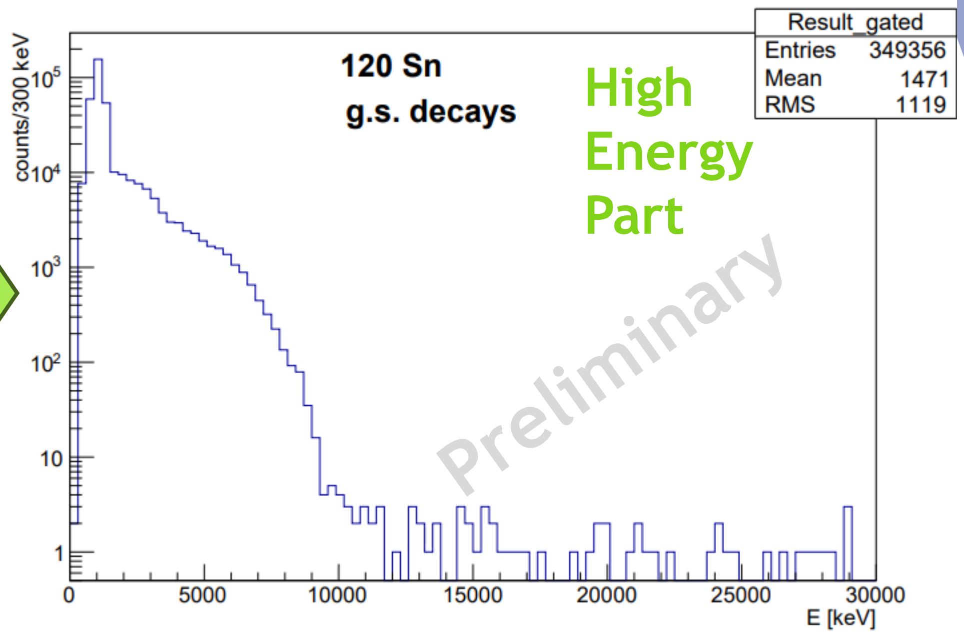


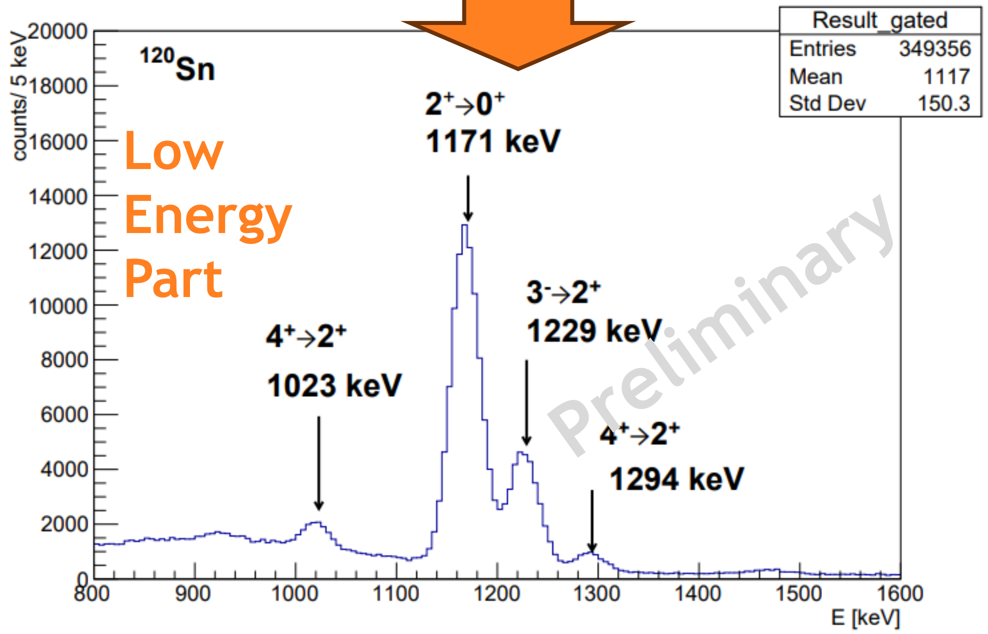
Search of ISGQR in ^{120}Sn



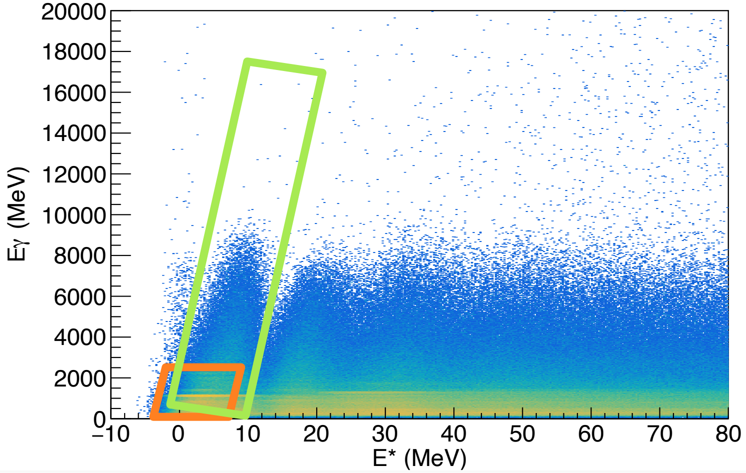
Search of ISGQR in ^{120}Sn

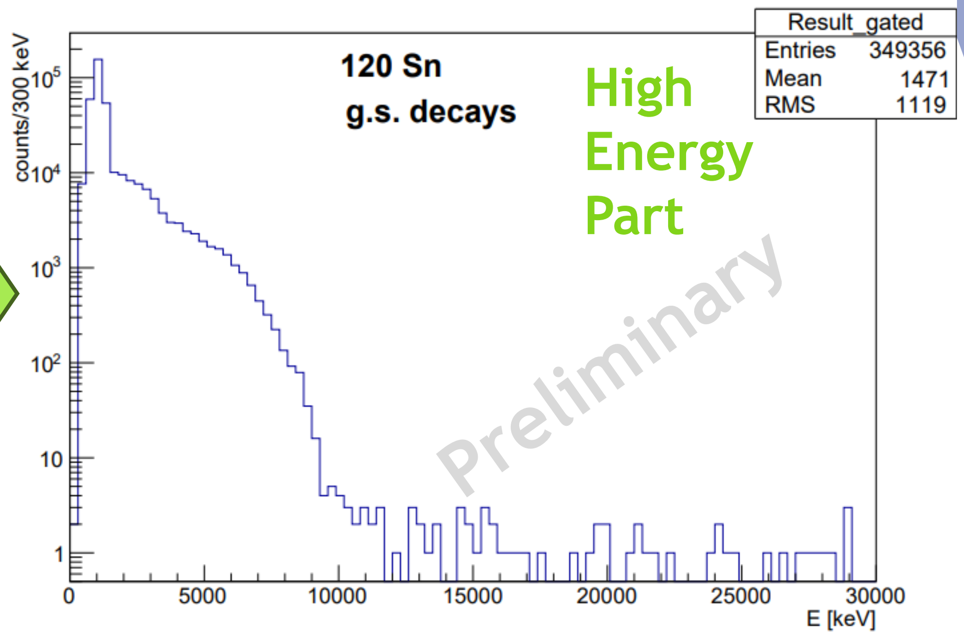


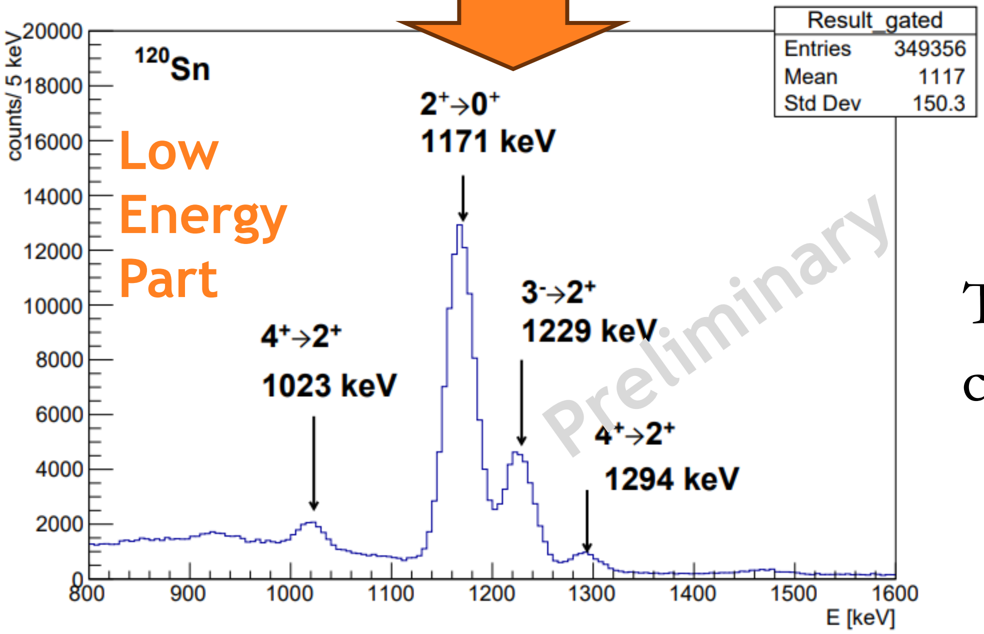




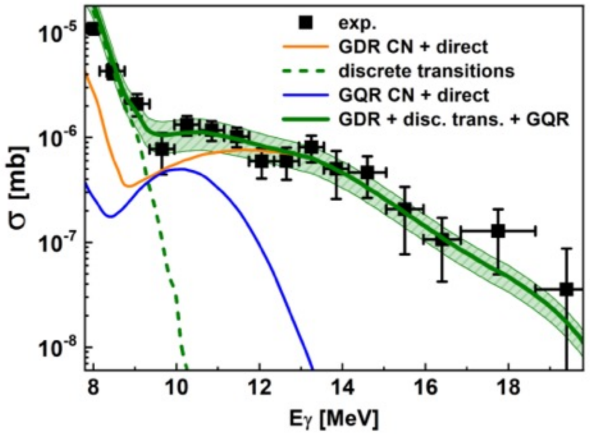
Search of ISGQR in ^{120}Sn



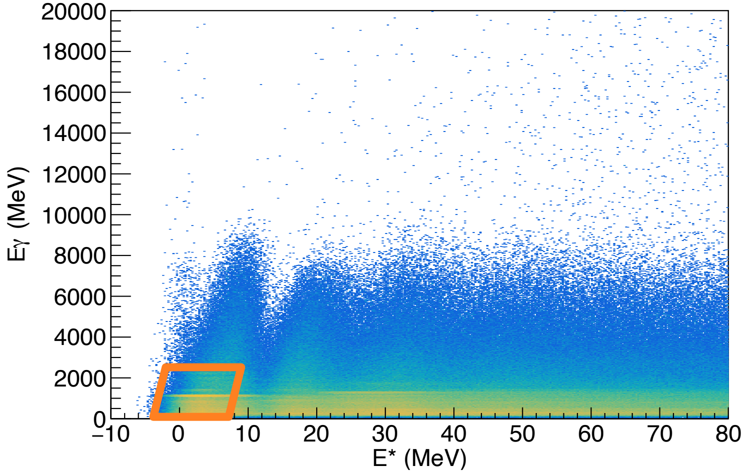


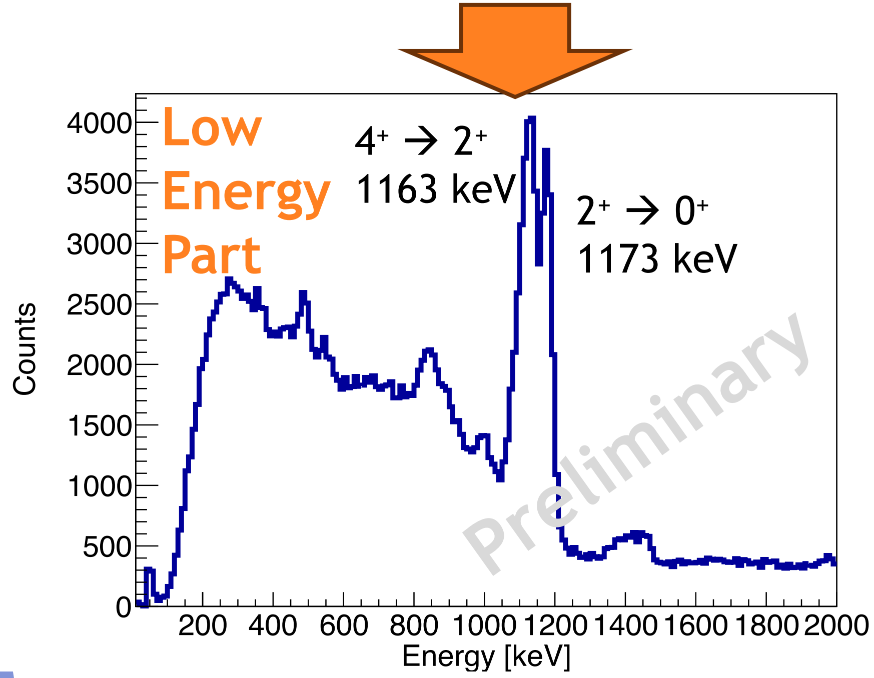


The different contributions has to be disantagled

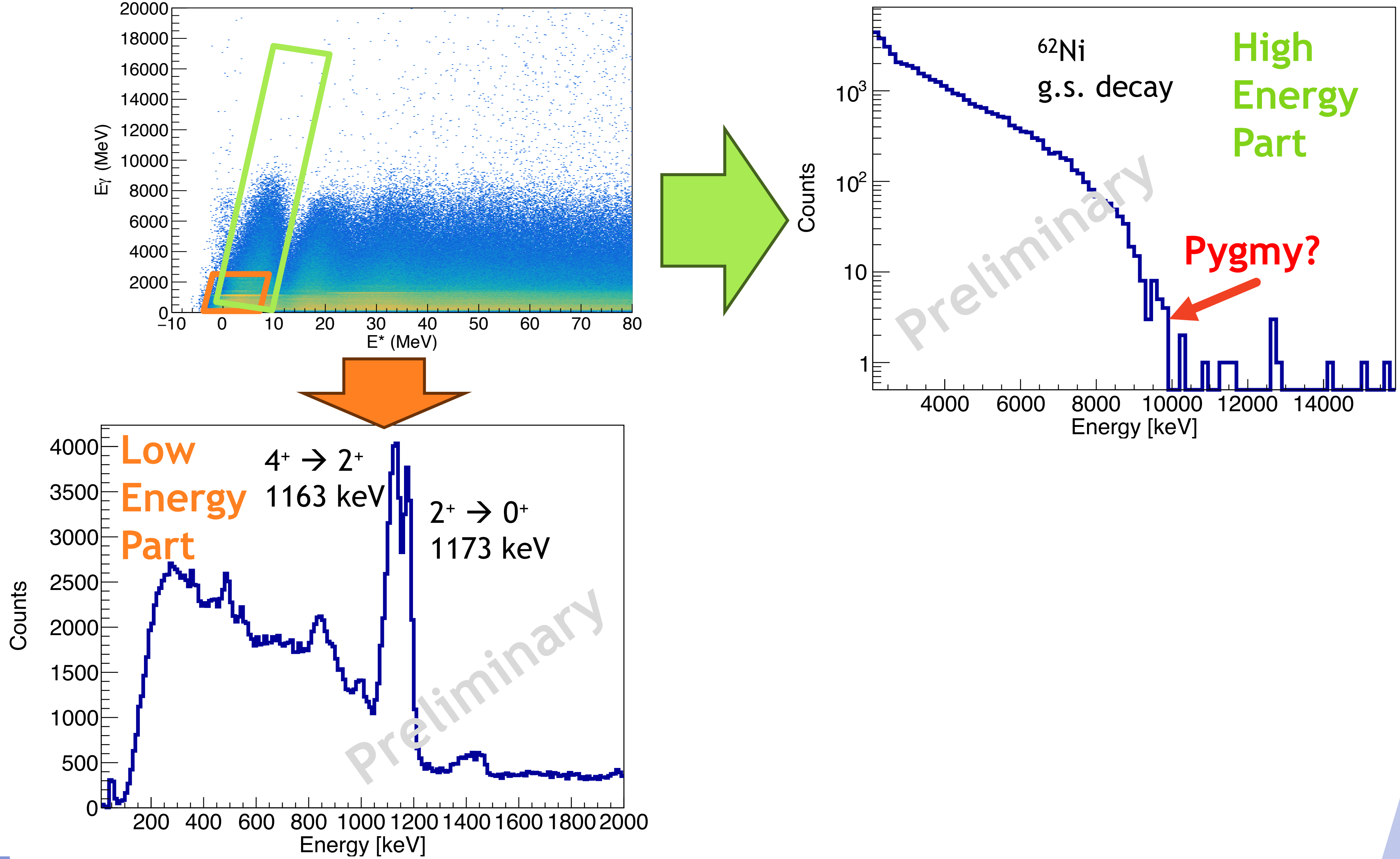


Pygmy in Ni isotopes

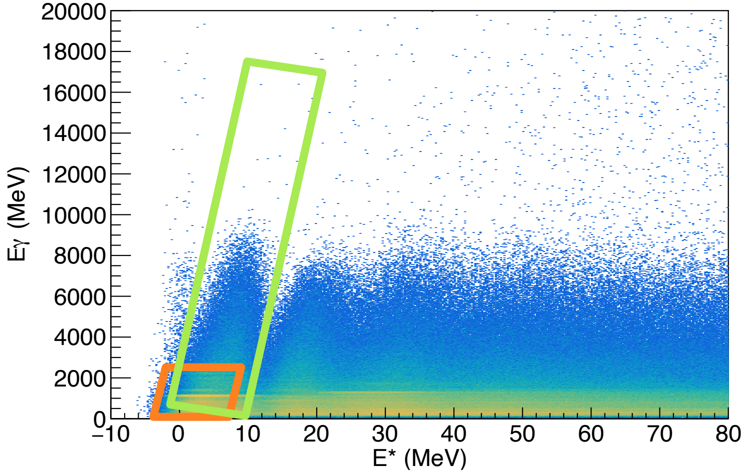


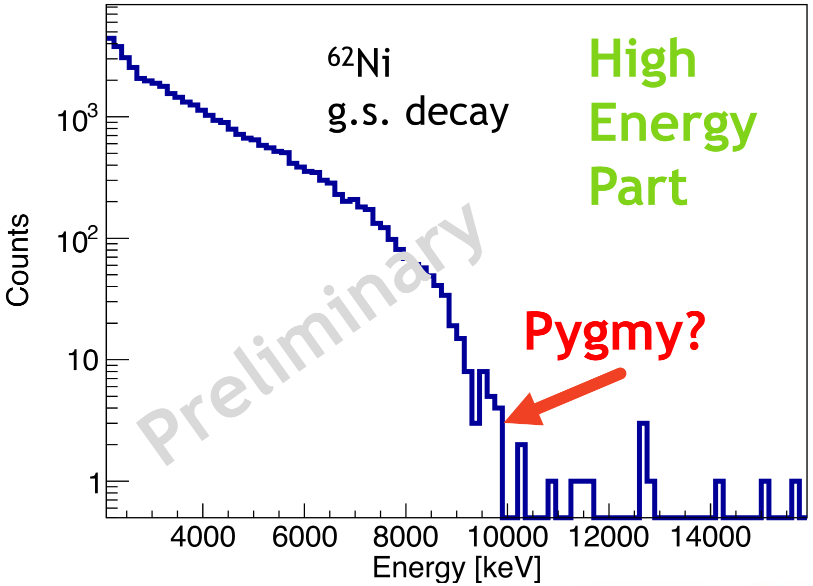


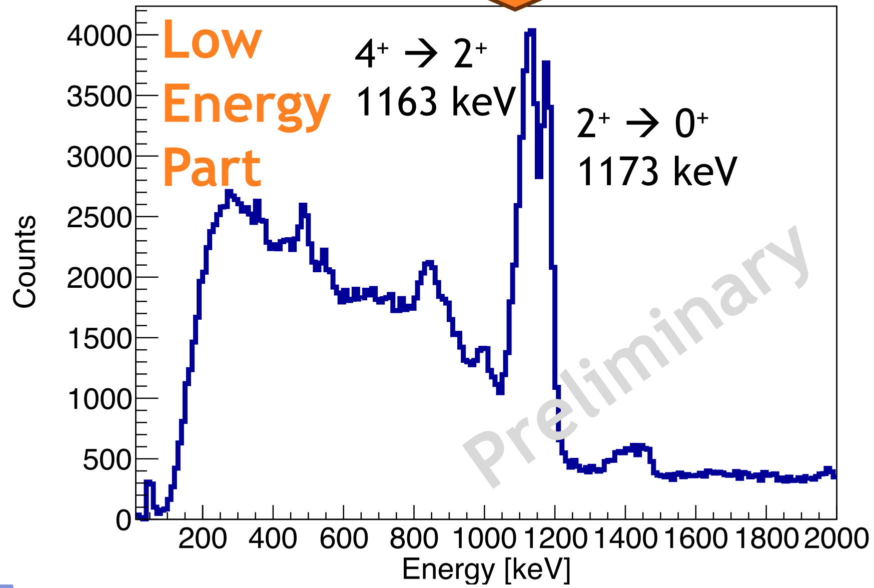
Pygmy in Ni isotopes

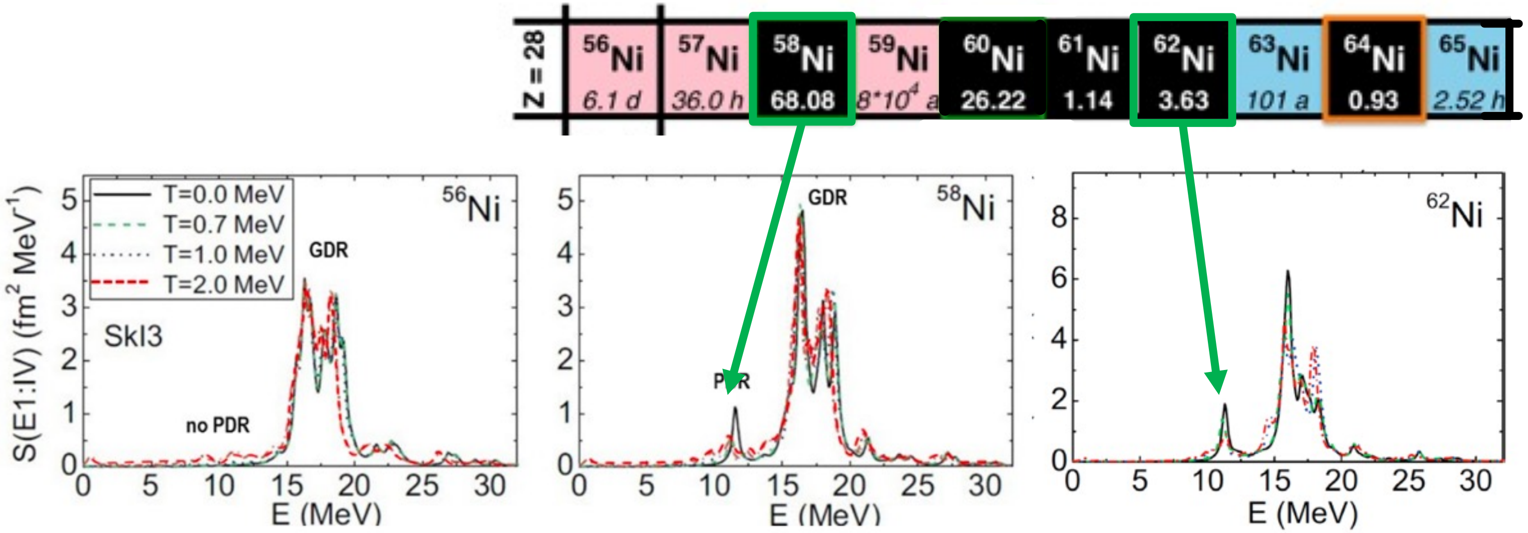


Pygmy in Ni isotopes









Conclusion

- **R&D on Scintillators**
  - **PARIS SiPM readout**: energy and time resolution comparable with the one with PMTs, predictable non-linearity, SiPM are not sensitive to magnetic field
  - **CLYC:** low fast neutron detection efficiency, issues with SiPM readout
- **Measurements of collective motions in nuclei with scintillators**
  - **Isospin mixing in ^{72}Kr:** data confirm the theory
  - **ISGQR in ^{120}Sn:** analysis ongoing
  - **PDR in ^{58}Ni and ^{62}Ni:** analysis ongoing