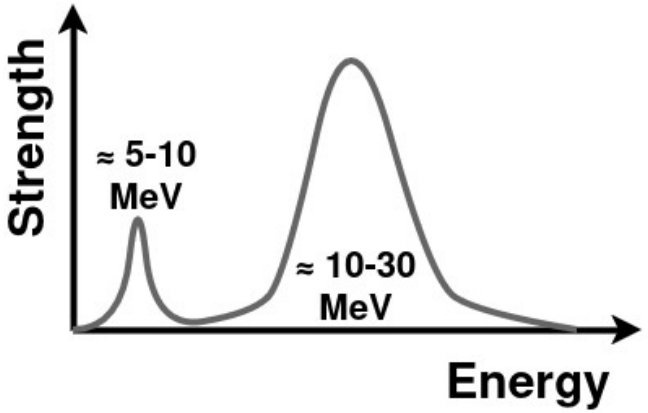
Probing the pygmy dipole resonance of 50Ca by Coulomb excitation

Introduction: Electric dipole response of nuclei

- Giant resonances → collective phenomenon observed in every nuclei

- Giant Dipole Resonance is a mode were proton and neutron vibrate in phase opposition



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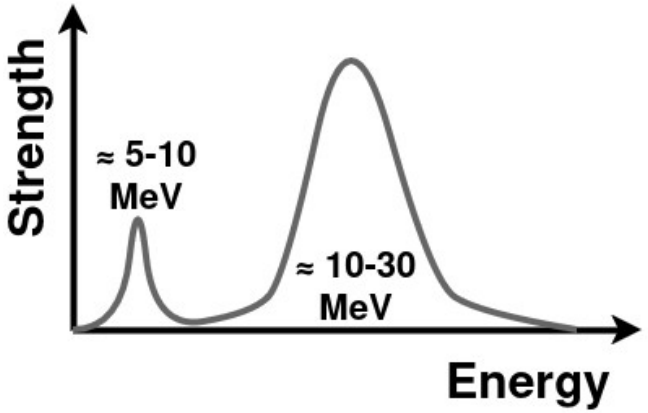
→ Pygmy Dipole Resonance (PDR)



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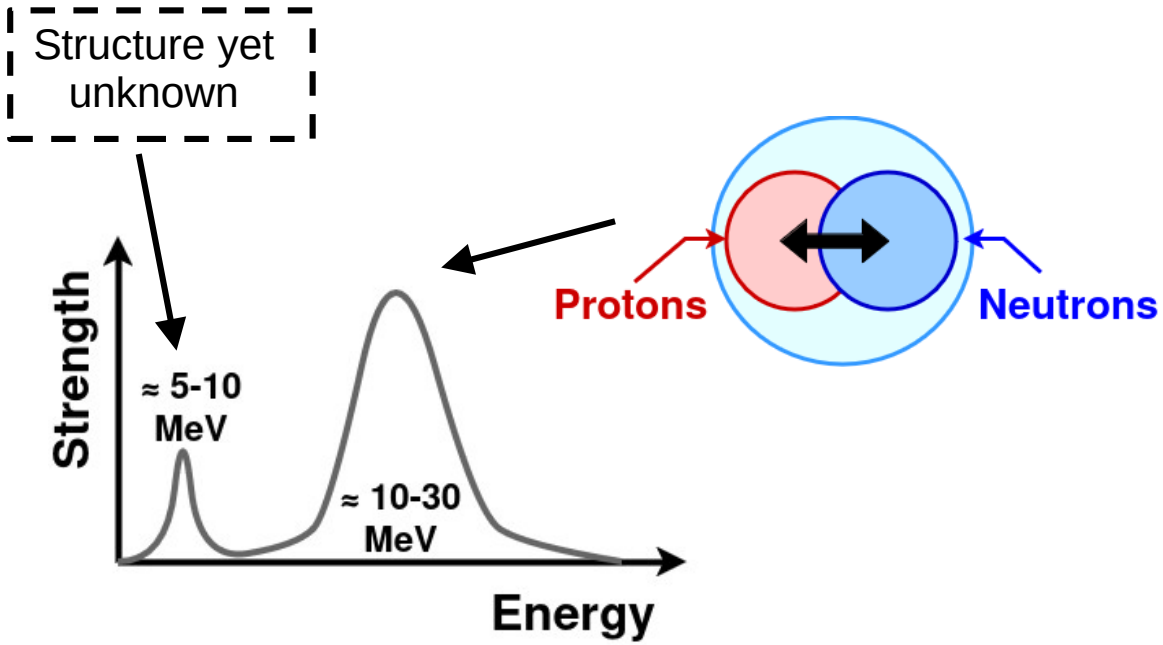

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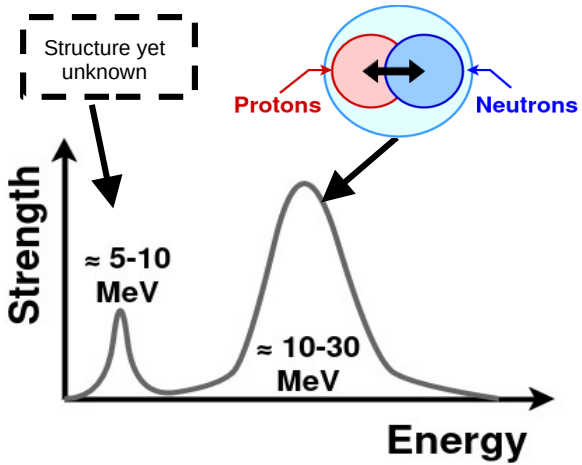
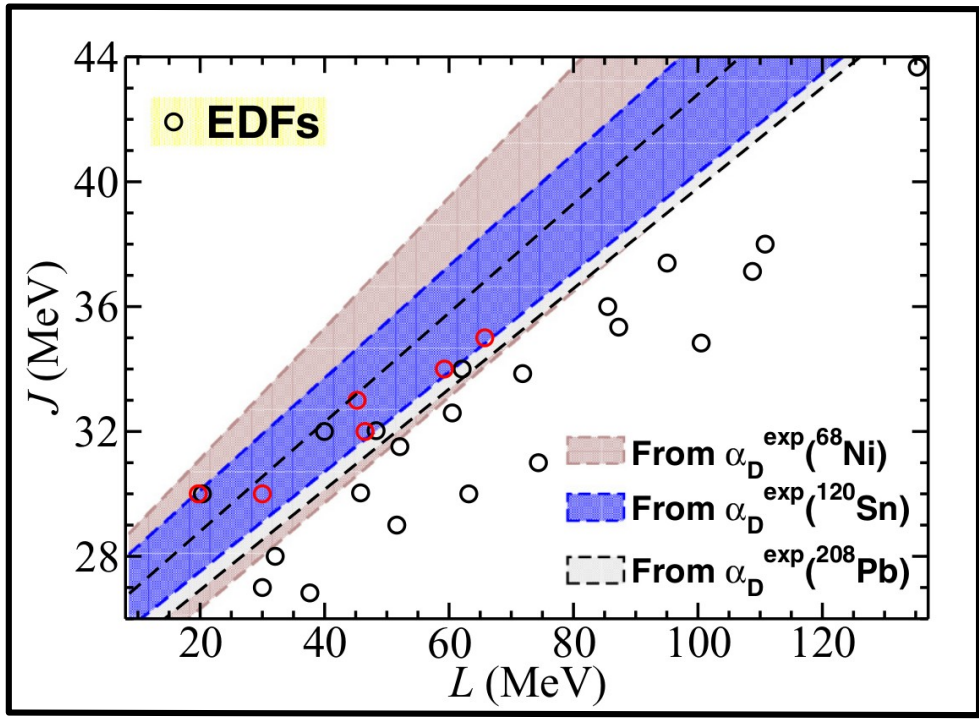
→ Pygmy Dipole Resonance (PDR)

- PDR → Constrain on density dependence of symmetry energy [**J. Piekarewicz, PRC 73 (2006), X.Roca-Maza, PRC 92(2015)**]



Dipole polarizibility:

$$\alpha_D = \frac{\hbar c}{2\pi} \int \frac{\sigma_{abs}}{E_x^2} dE_x$$



Extracted from:
[X.Roca-Maza, PRC 92(2015)]

Introduction: Electric dipole response of nuclei

- In [**Egorova, PRC 94 (2016)**, **Inakura PRC 84 (2011)**] it is shown that a sudden change in the PDR strength may arise

- Certain neutron orbits enhance the PDR
  → Shell effect

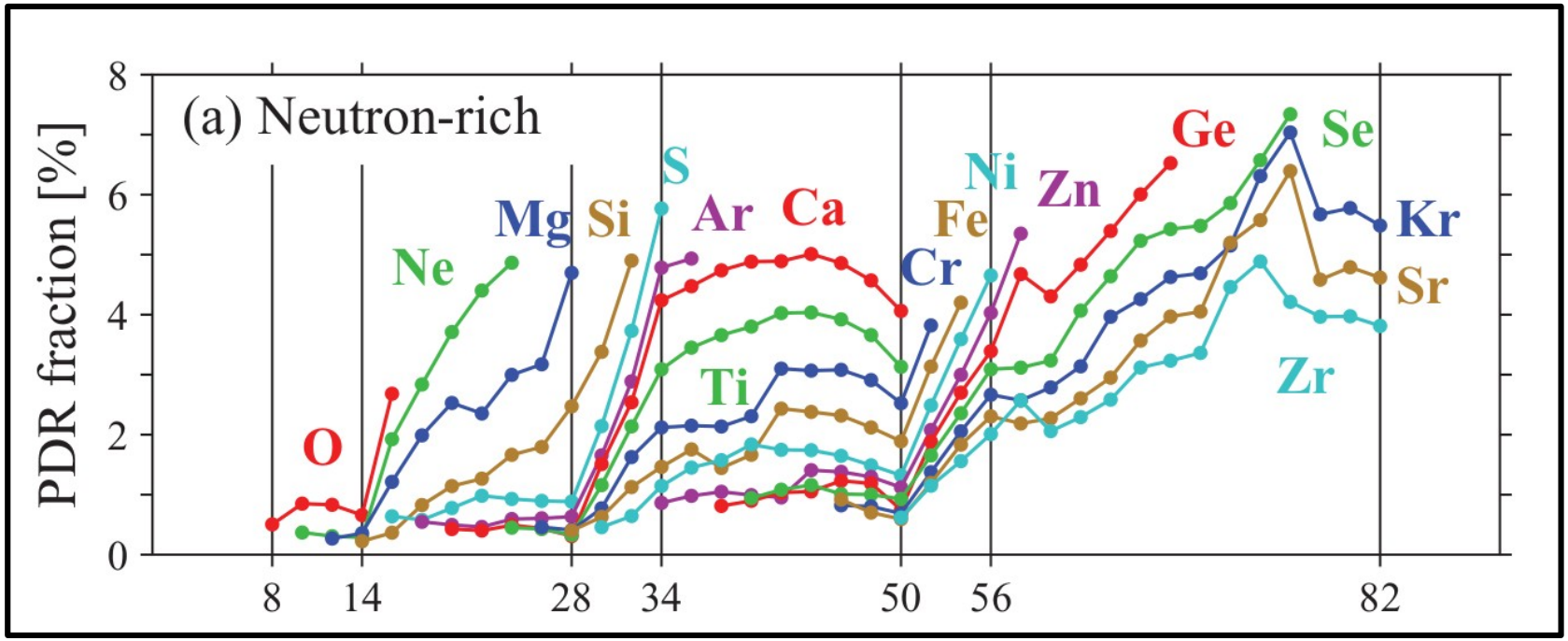
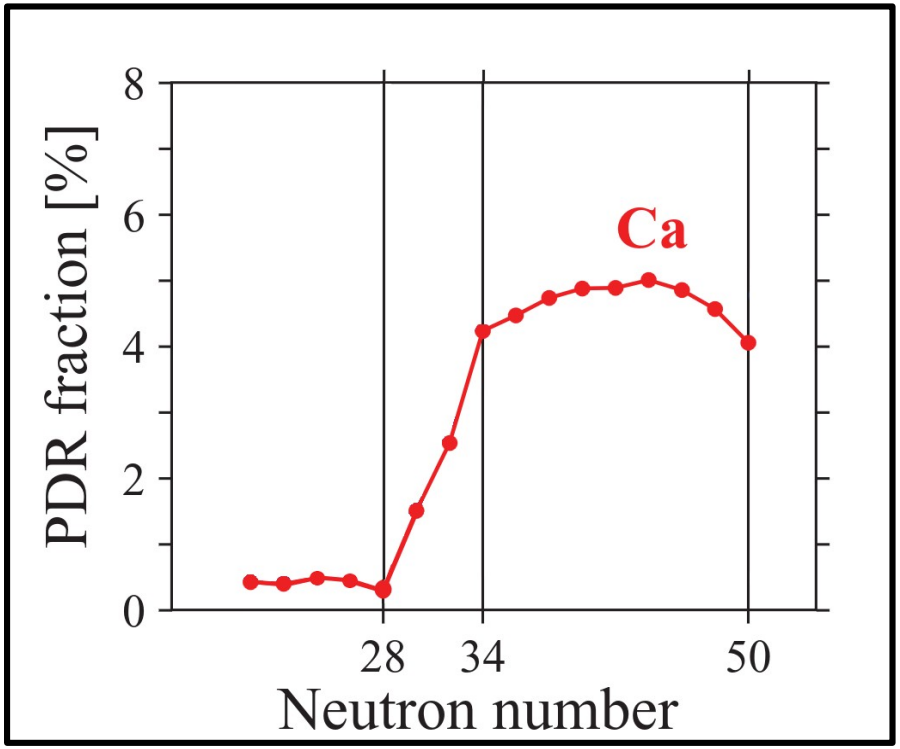


Fig. 2 from ***[Inakura PRC 84 (2011)]***

Introduction: Electric dipole response of nuclei

- In [**Egorova, PRC 94 (2016)**, **Inakura PRC 84 (2011)**] it is shown that a sudden change in the PDR strength may arise
- Certain neutron orbits enhance the PDR
  → Shell effect

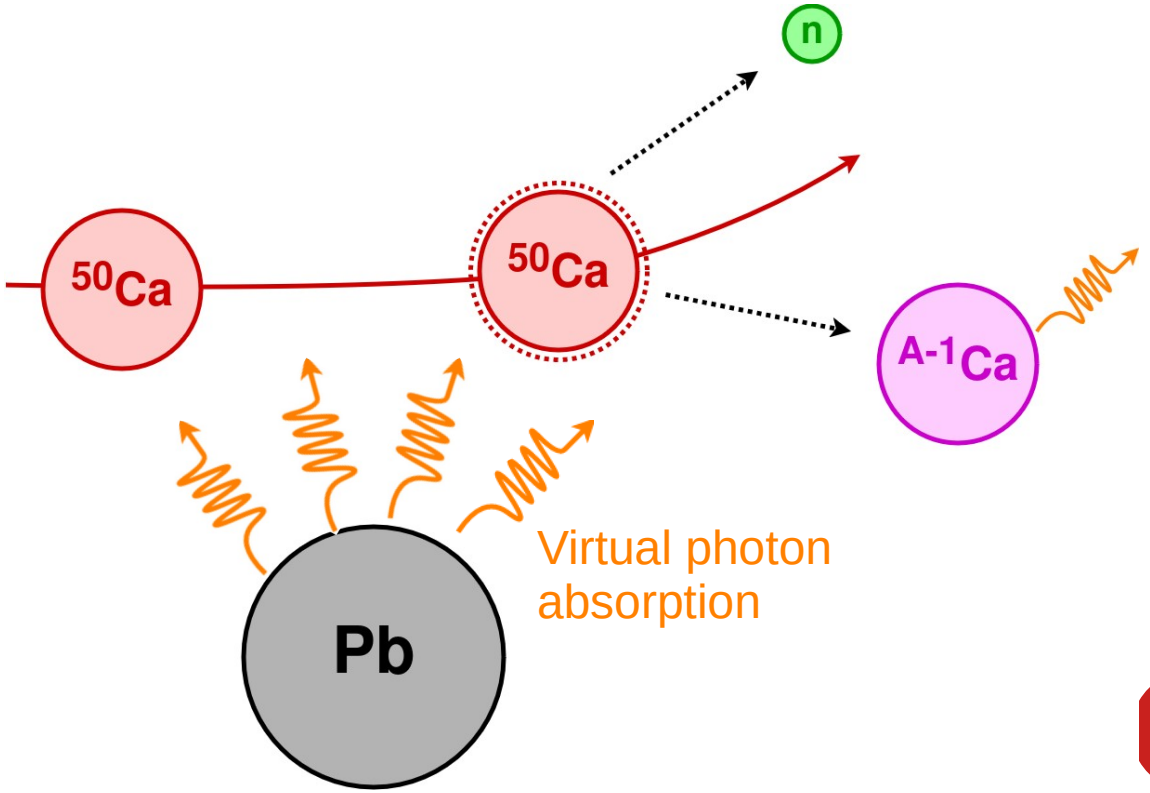
  → Study of ^{52,50}Ca PDR by Coulomb excitation
- Focus on ^{50}Ca in this presentation



*Adapted from **[Inakura PRC 84 (2011)]***

Introduction: Coulomb excitation

- Inverse kinematics on Pb target
- Virtual photon absorption by 50Ca
  → **^{50}Ca velocity ~ 0.6c**
  → Relativistic one-step interaction



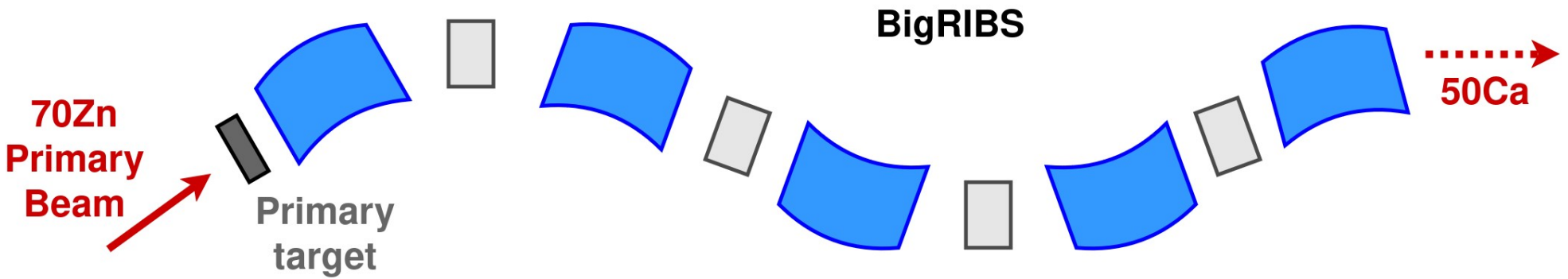
Invariant mass spectroscopy:

$$E_x\left(^{50}Ca\right) = \sum_i^N E_\gamma^i + \sum_i^N E_n^i + S_n$$

Introduction: The experiment

- Experiment → RIKEN - RIBF
- ^{70}Zn primary beam on thick Be target
- Fragment separated in flight by BigRIBS (Radioactive Ion Beam Separator)

  → Secondary beam of ^{50}Ca @ 223 MeV/A



Introduction: The experiment

- ^{70}Zn primary beam on thick Be target
- Fragment separated in flight by BigRIBS

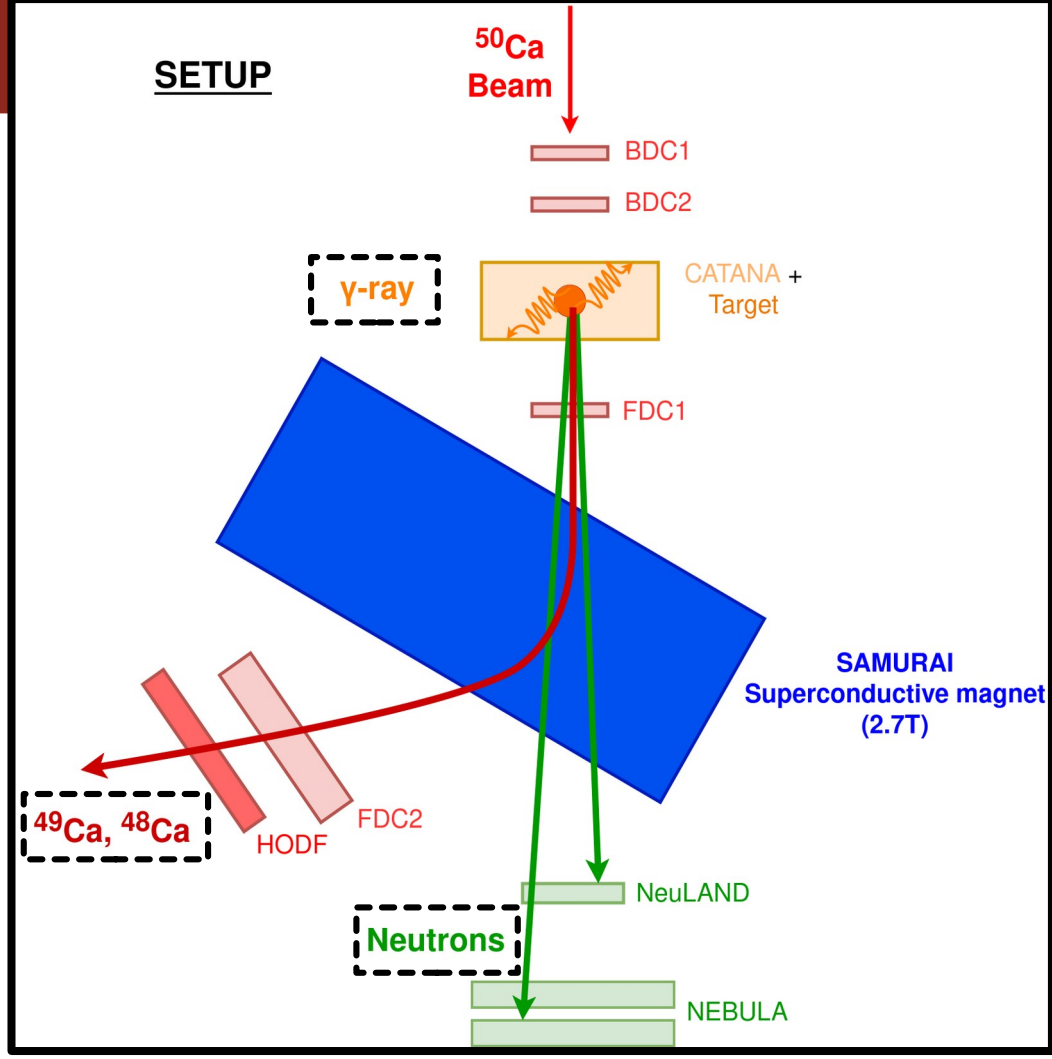
  → Secondary beam of ^{50}Ca @ 223 MeV/A

- Targets → **Pb, C** (+ background measurement)

  → Invariant mass spectroscopy:

$$E_x(^{50}Ca) = \sum_i^N E_\gamma^i + \sum_i^N E_n^i + S_n$$

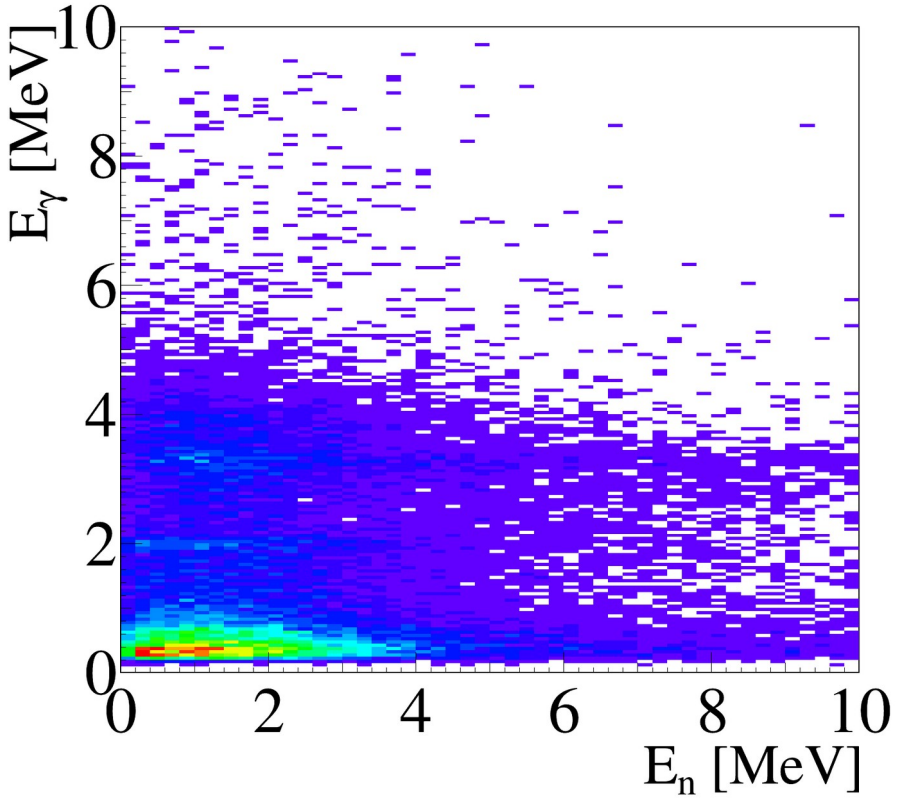
- **NeuLAND + NEBULA** → Plastic scintillator wall → Neutron detection
- **BDCs + FDCs + HODF** → Beam and fragment tracking, and particle identification



Results

Results for 49Ca+n: ɣ and neutron energy spectra

- **<u>49Ca+n channel (Pb target):</u>**



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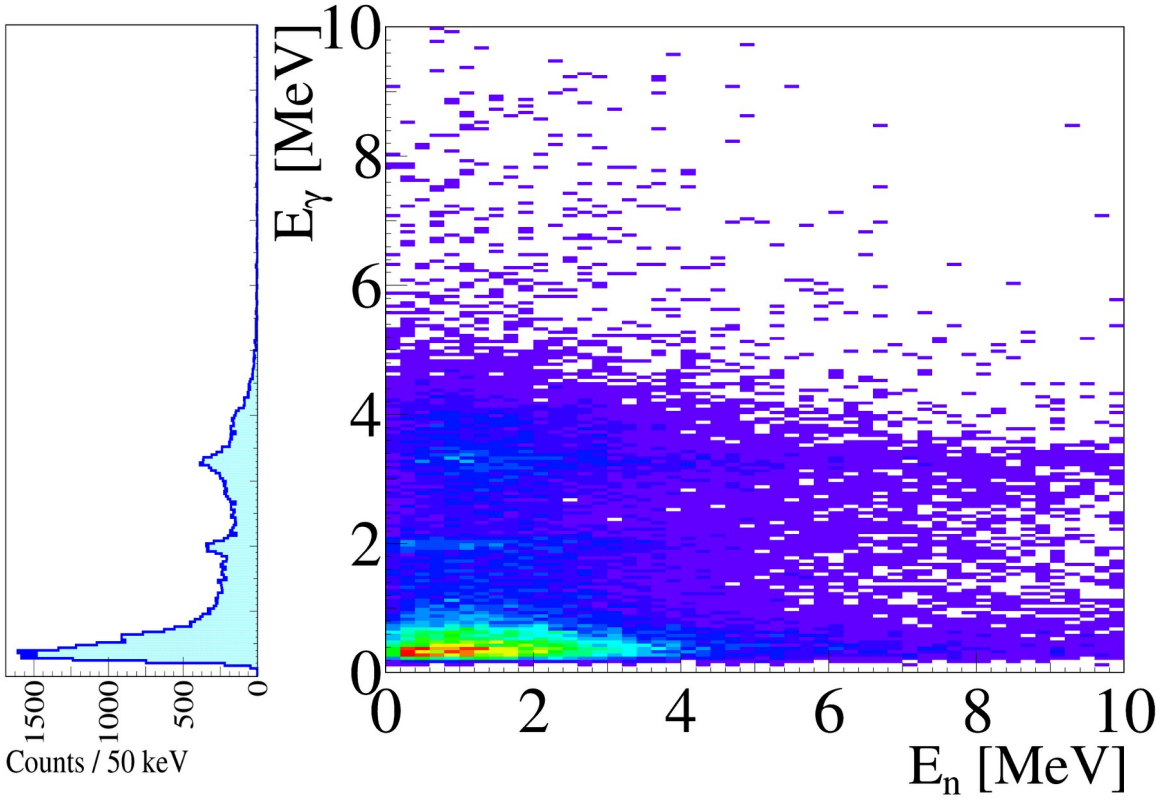

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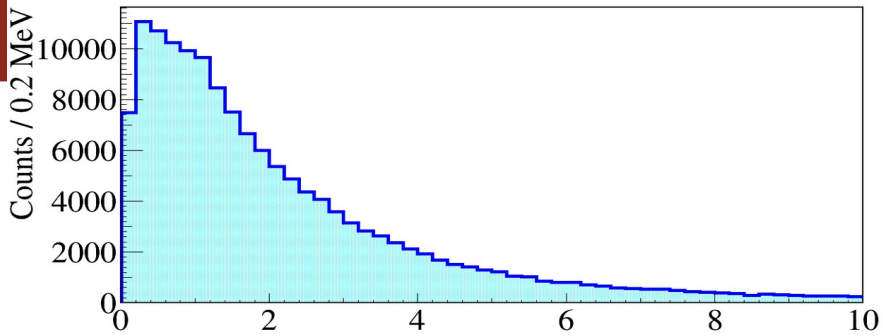
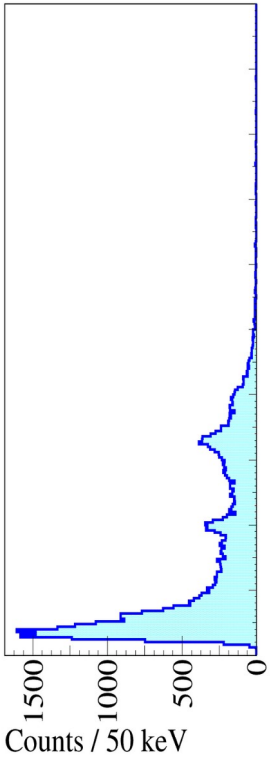
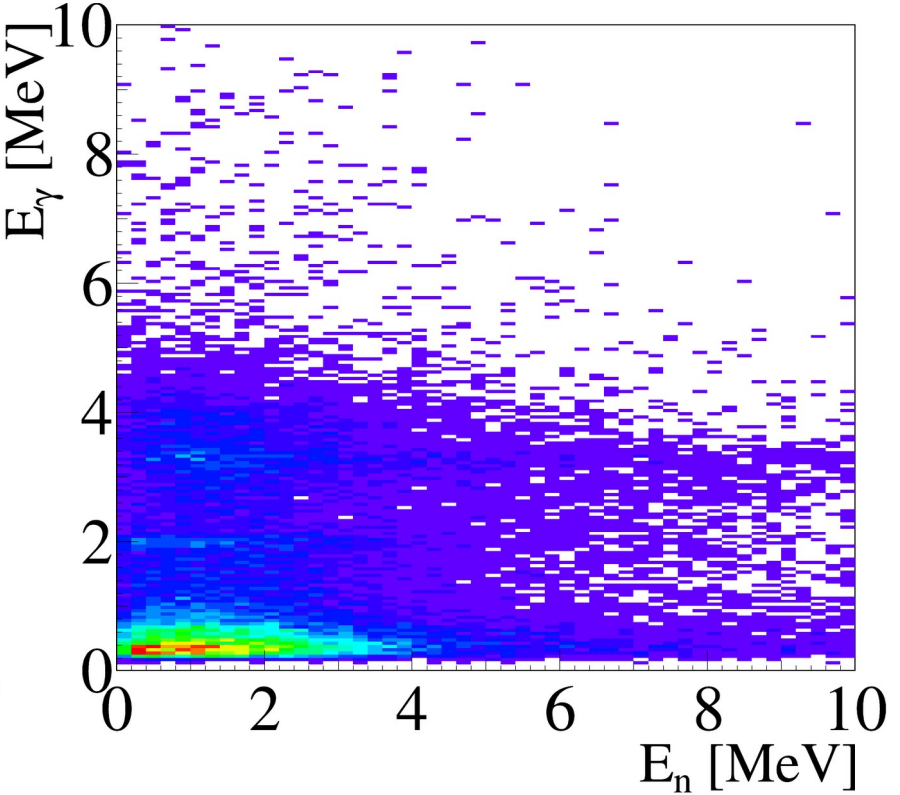
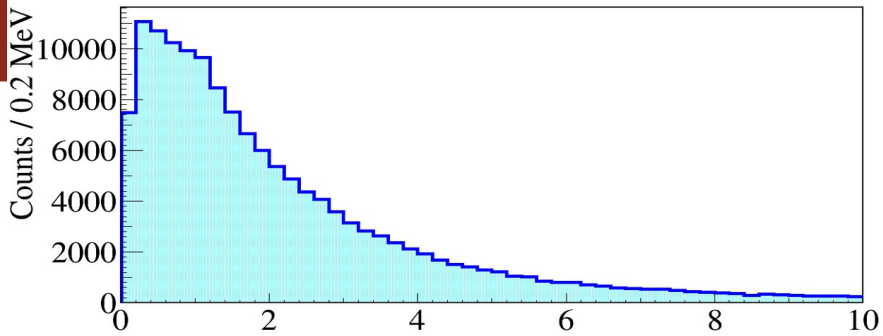


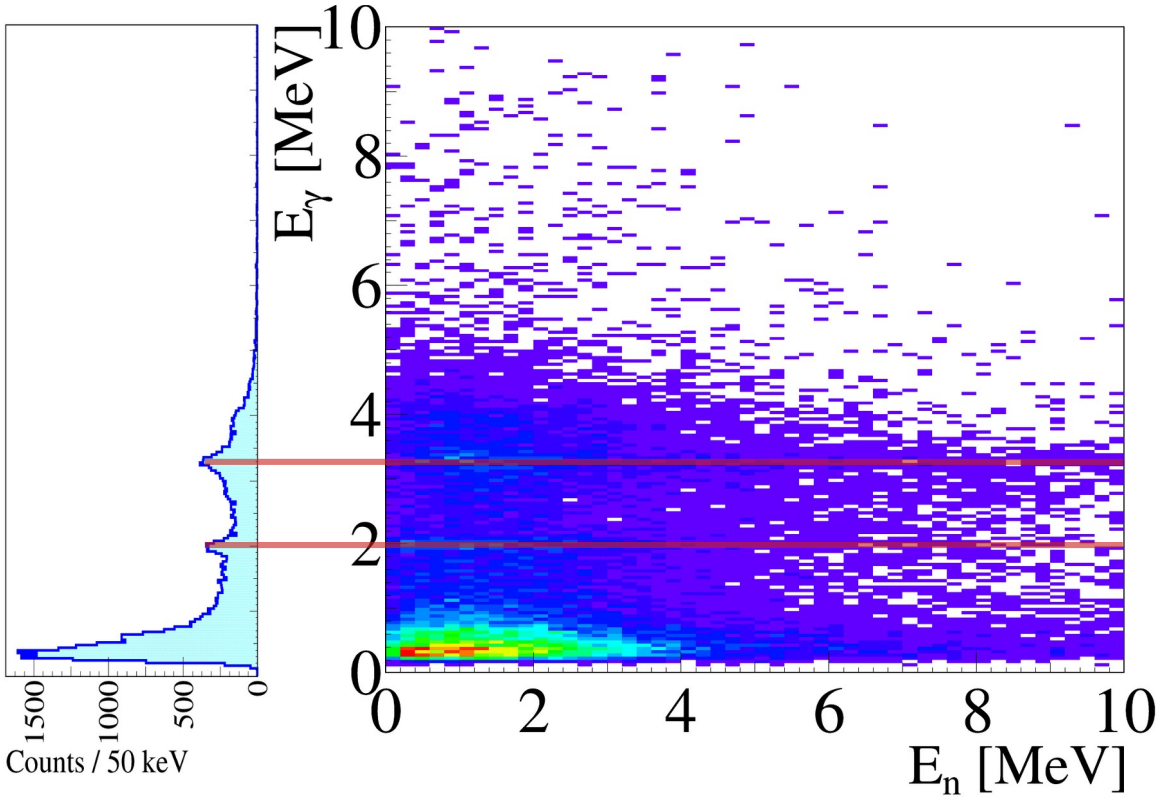




Results for 49Ca+n: ɣ and neutron energy spectra

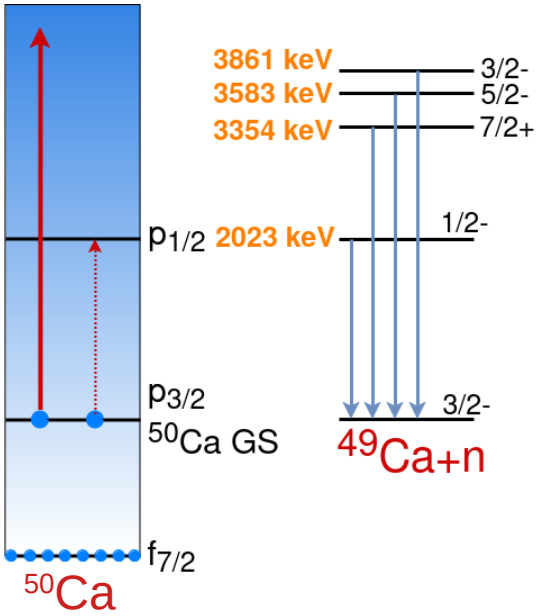
- **<u>49Ca+n channel (Pb target):</u>**
- 2 strong correlation of $E_ɣ$ and E_n at $E_ɣ$ = 2.0 MeV and $E_ɣ$ = 3.3 MeV

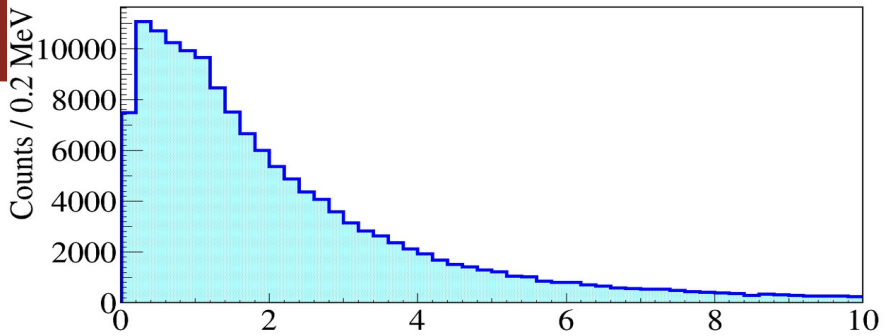


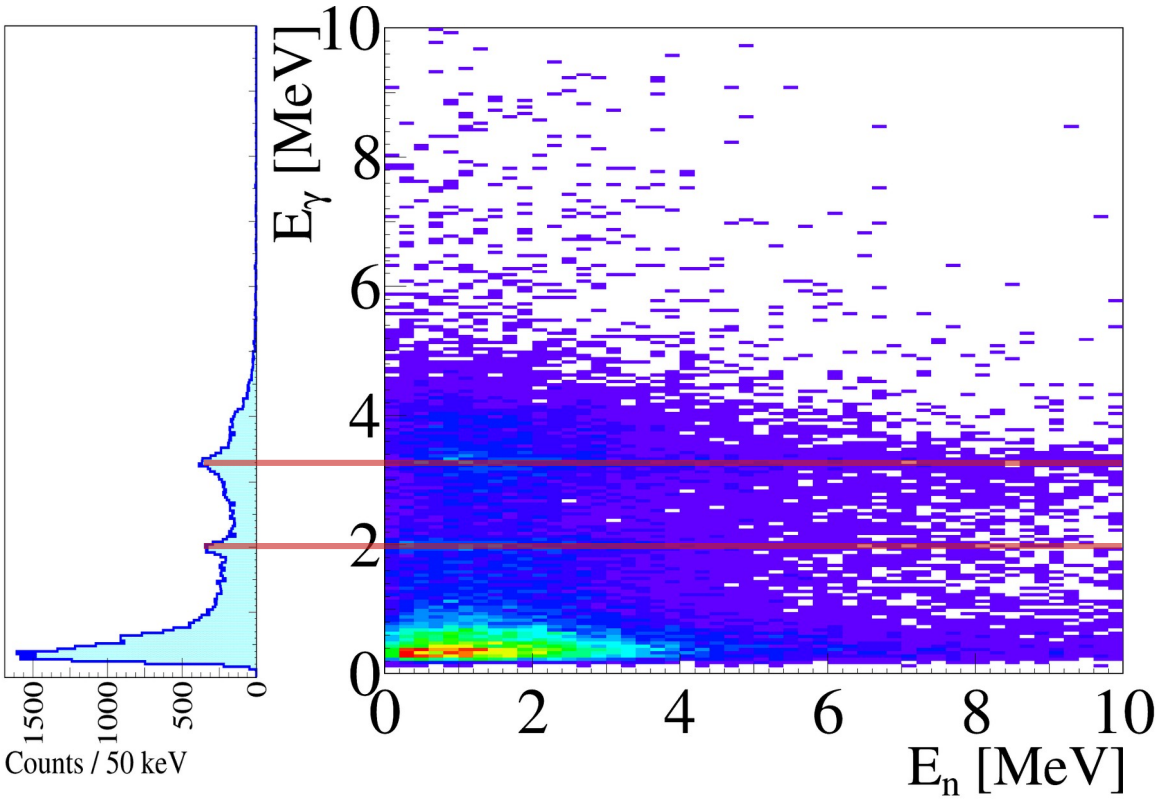


Results for 49Ca+n: ɣ and neutron energy spectra

- **<u>49Ca+n channel (Pb target):</u>**
- 2 strong correlation of $E_ɣ$ and E_n at $E_ɣ$ = 2.0 MeV and $E_ɣ$ = 3.3 MeV
- High population of first excited state of 49Ca → Indication of statistical decay (2p-2h state)

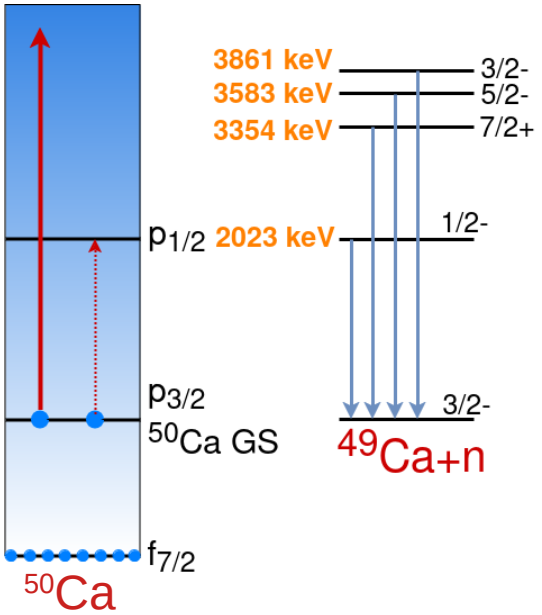


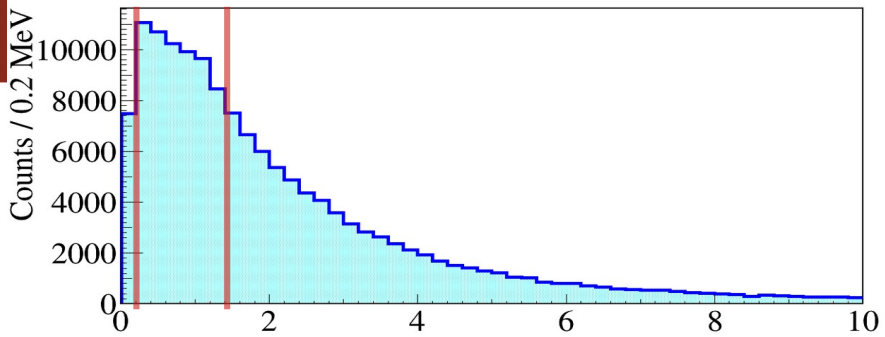


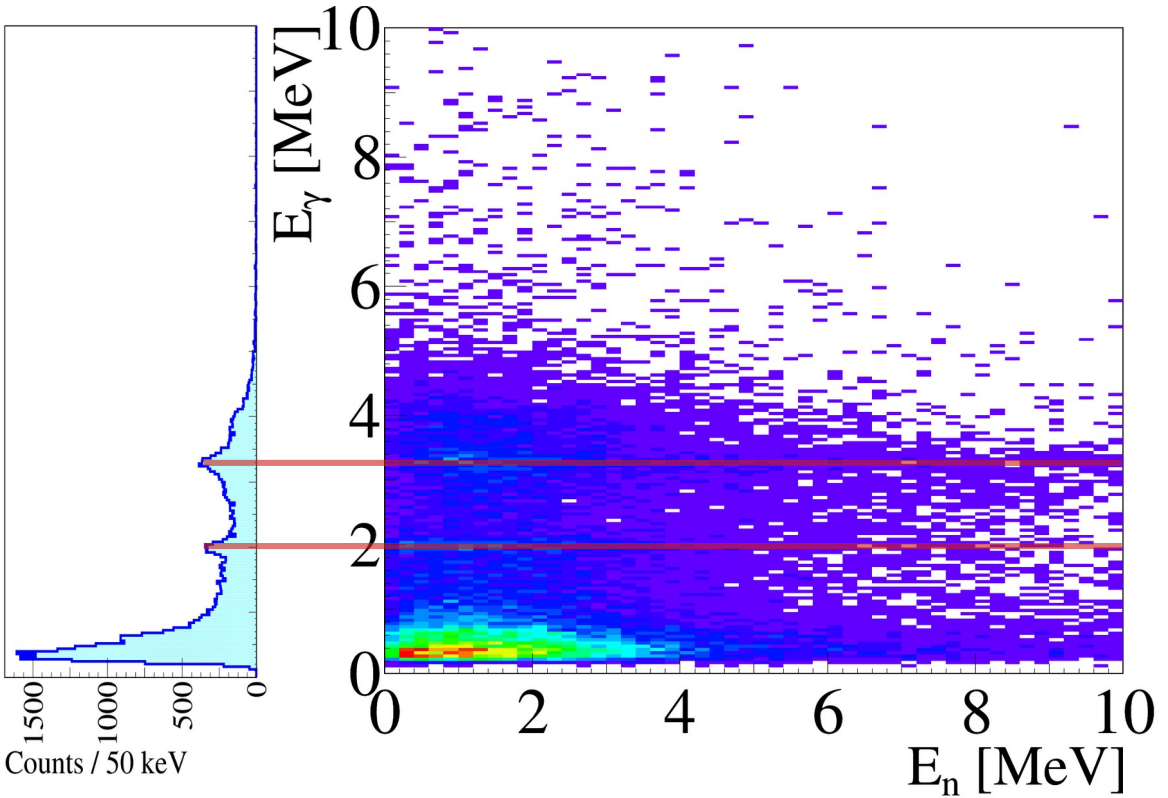


Results for 49Ca+n: ɣ and neutron energy spectra

- **<u>49Ca+n channel (Pb target):</u>**
- 2 strong correlation of $E_ɣ$ and E_n at $E_ɣ$ = 2.0 MeV and $E_ɣ$ = 3.3 MeV
- High population of first excited state of 49Ca → Indication of statistical decay (2p-2h state)
- En spectra → Structure at low energy (more details further)

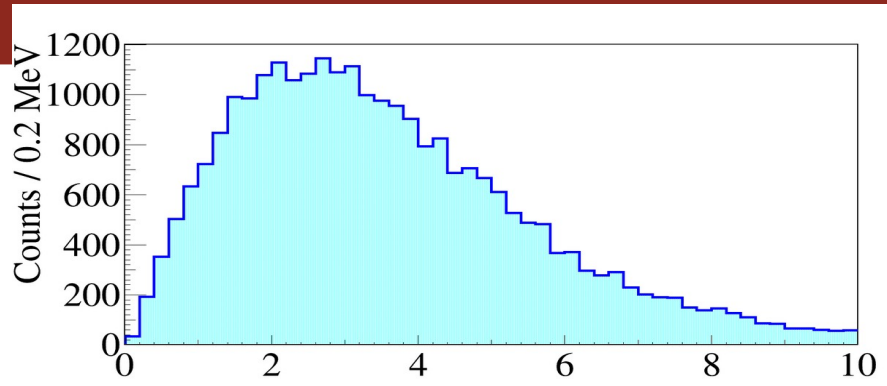


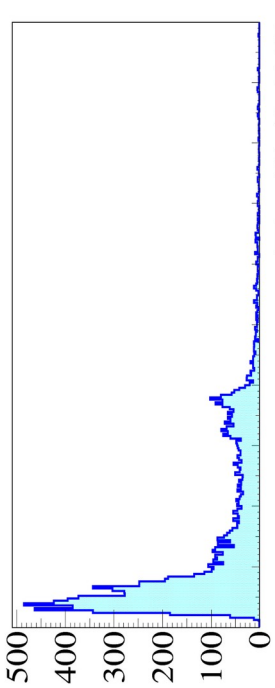


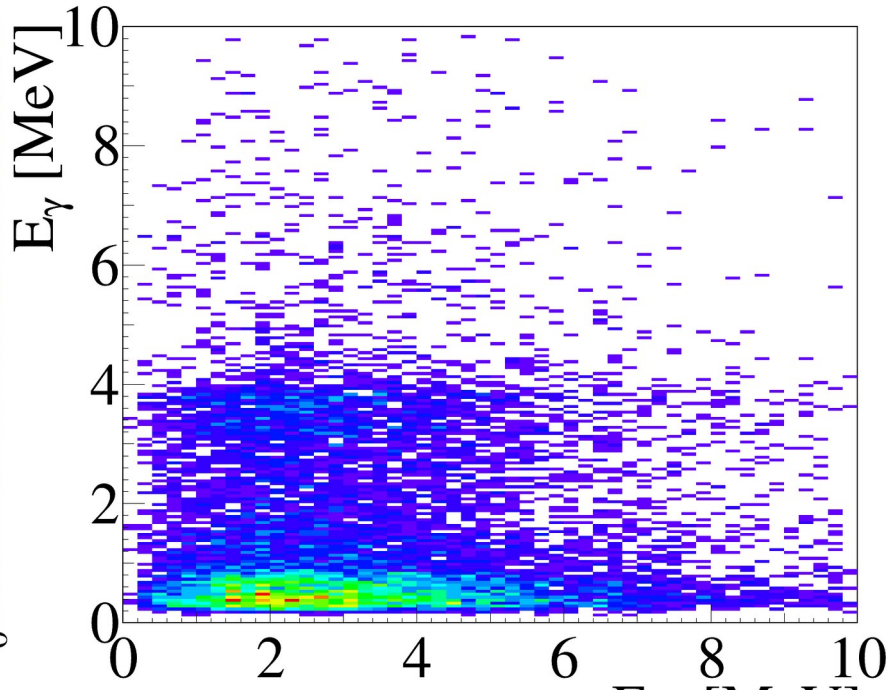


Results for 48Ca+n+n

- **48Ca+n+n channel (Pb target):**

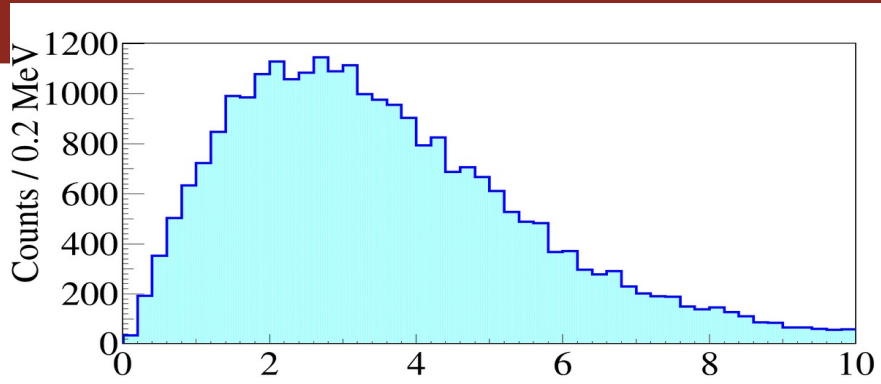


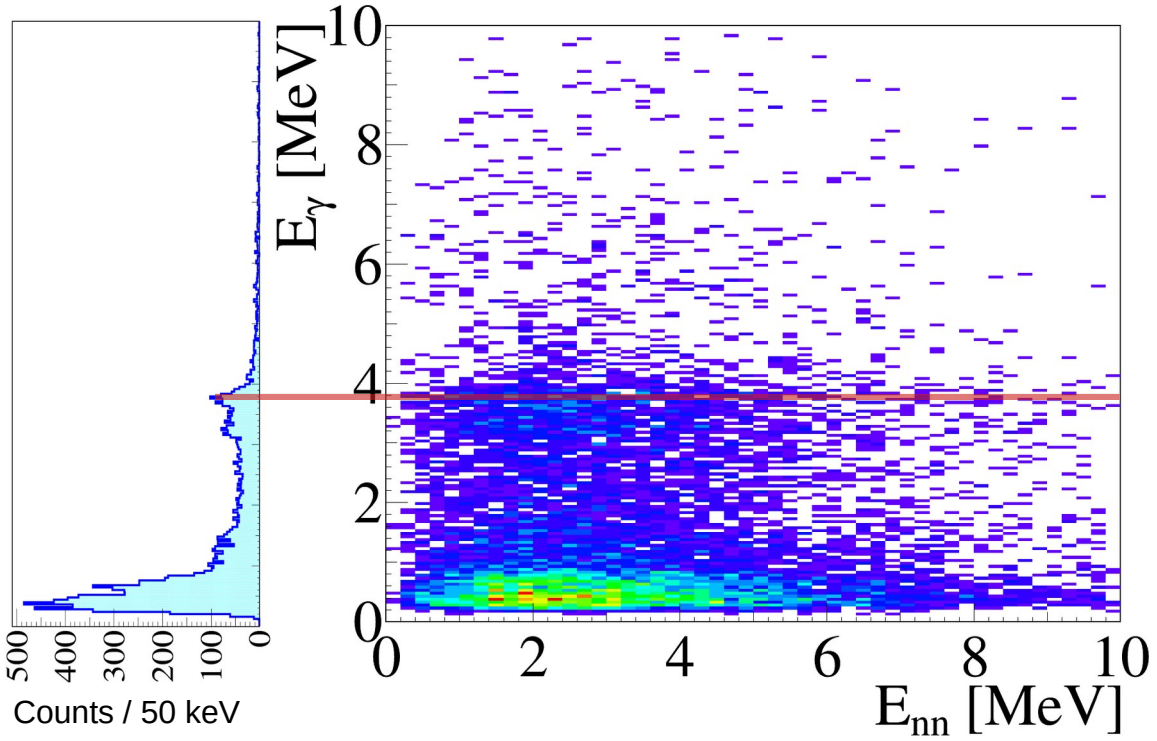


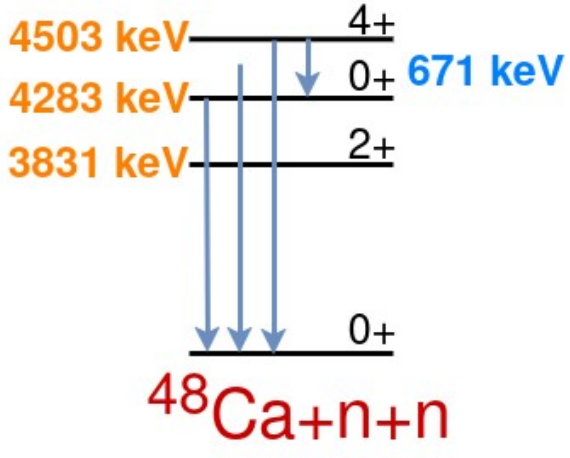


Results for 48Ca+n+n

- **48Ca+n+n channel (Pb target):**
- Strong correlation of E_γ with E_{nn} at E_γ = 3.8 MeV (^{48}Ca first excited state)
  - Width of peak → addback algorithm efficiency

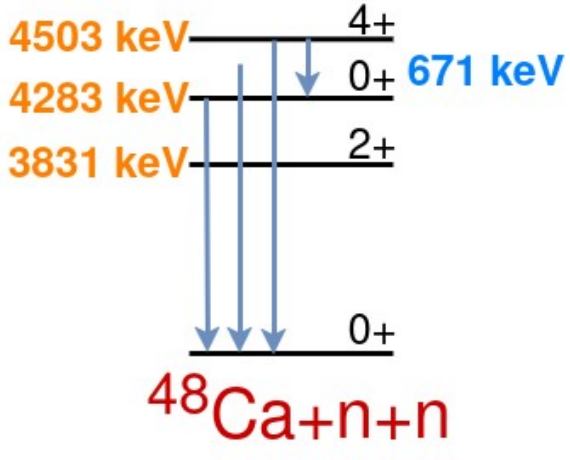


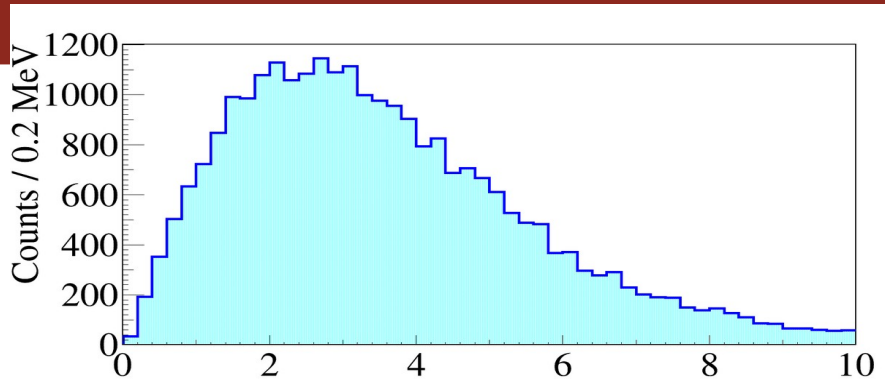


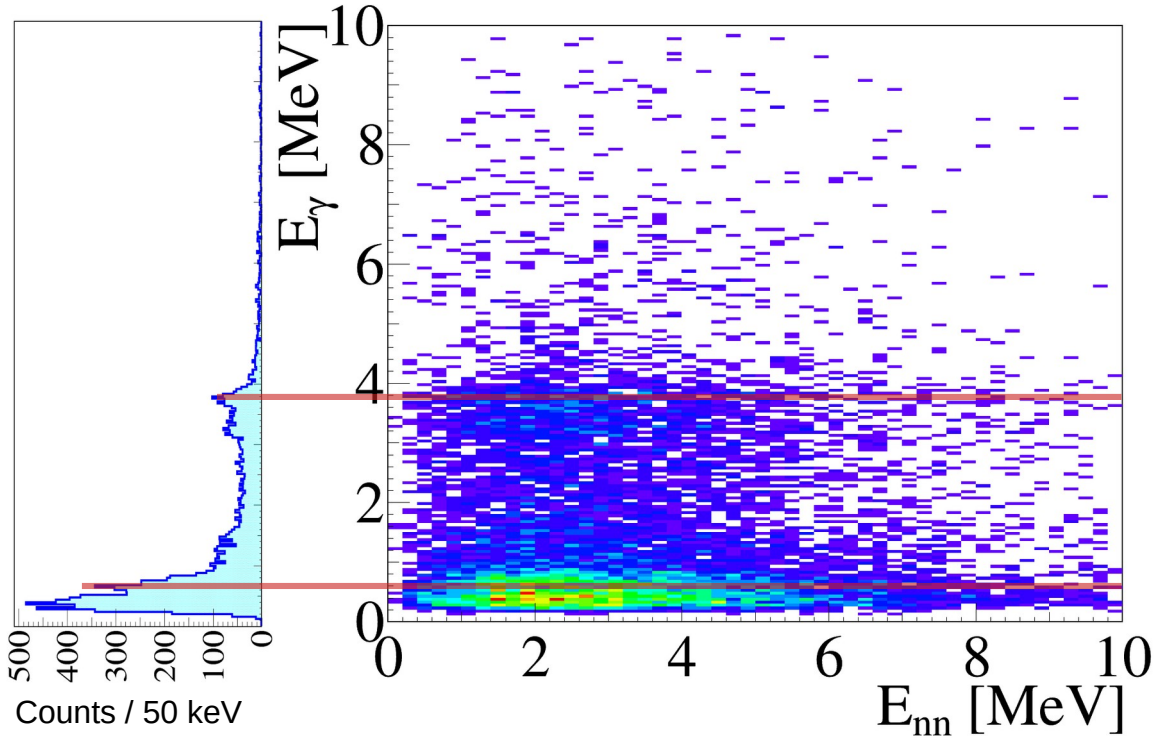


Results for 48Ca+n+n

- **<u>48Ca+n+n channel (Pb target):</u>**
- Strong correlation of E_γ with E_{nn} at E_γ = 3.8 MeV (^{48}Ca first excited state)
  - Width of peak → addback algorithm efficiency
- Peak at $E_\gamma \approx 700$ keV → transition at higher energies

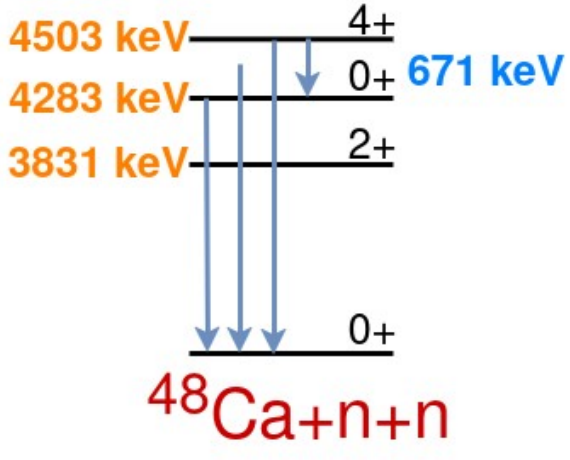


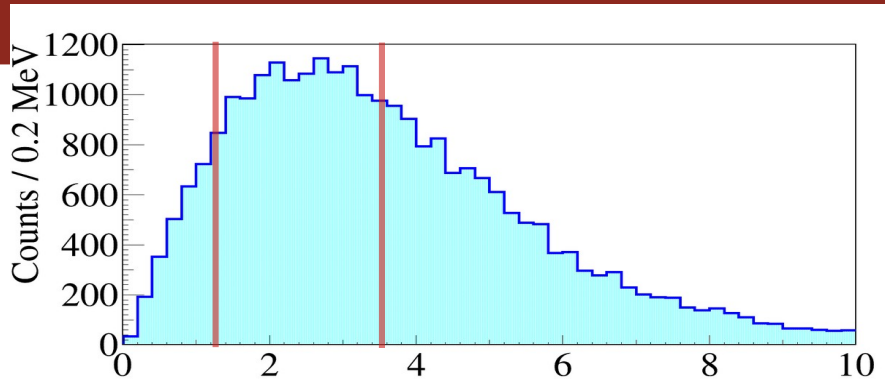


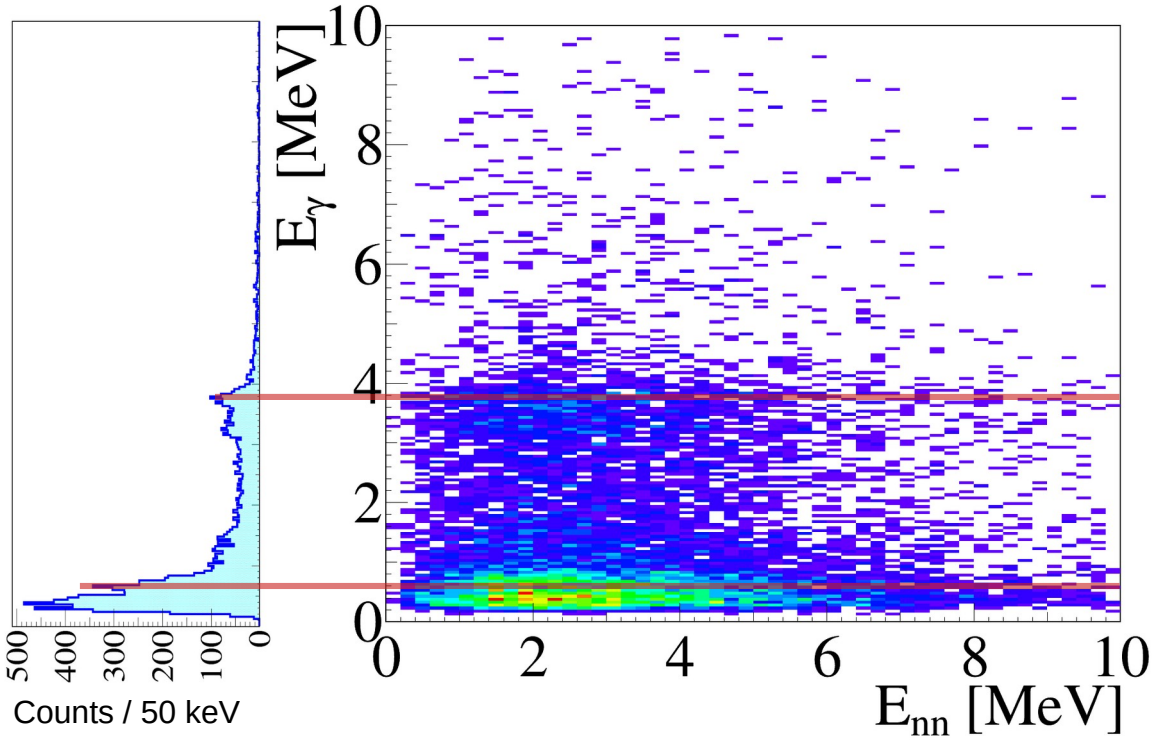


Results for 48Ca+n+n

- **48Ca+n+n channel (Pb target):**
- Strong correlation of E_γ with En at E_γ = 3.8 MeV (^{48}Ca first excited state)
  - Width of peak → addback algorithm efficiency
- Peak at E_γ = 700 keV → transition at higher energies
- Wide structure around E_{nn} = 2.5 MeV







Results: Inclusive cross sections

Inclusive cross section determined
→ Uncertainties: statistical and systematic

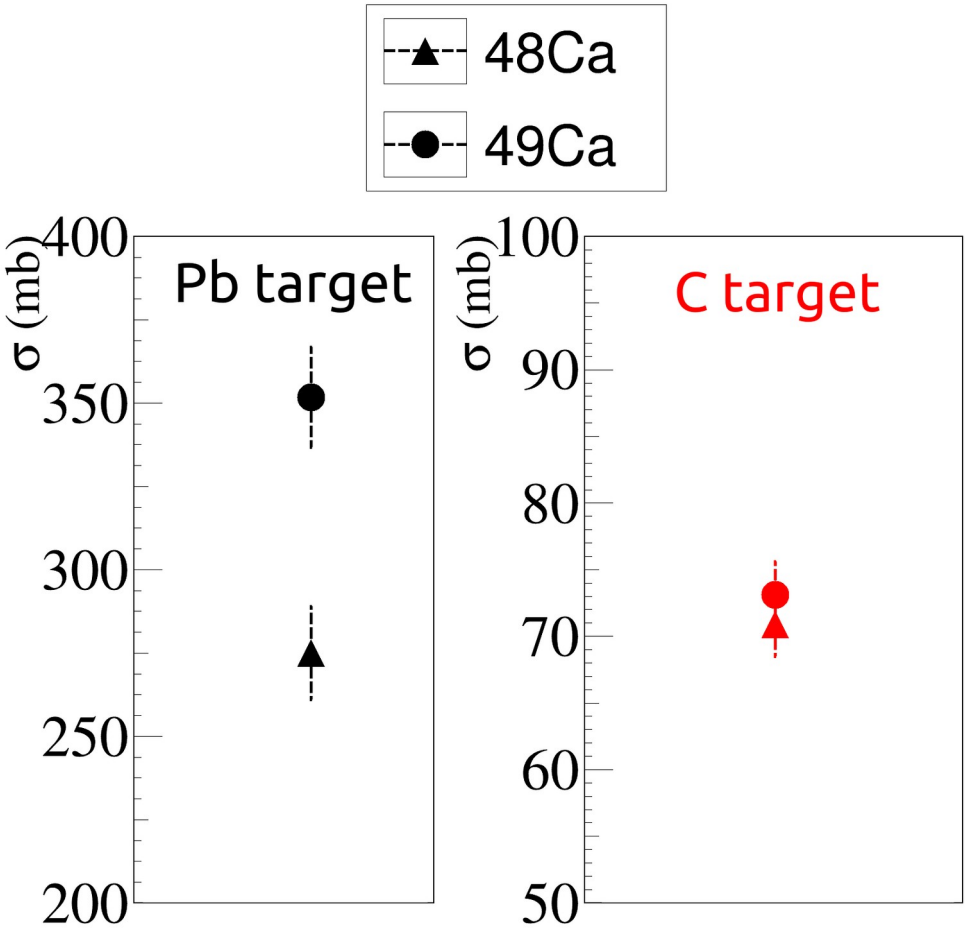
<u>For Pb Target:</u>

$\sigma_{inc}(^{49}Ca) > \sigma_{inc}(^{48}Ca)$

<u>For C Target:</u>

$\sigma_{inc}(^{49}Ca) \approx \sigma_{inc}(^{48}Ca)$

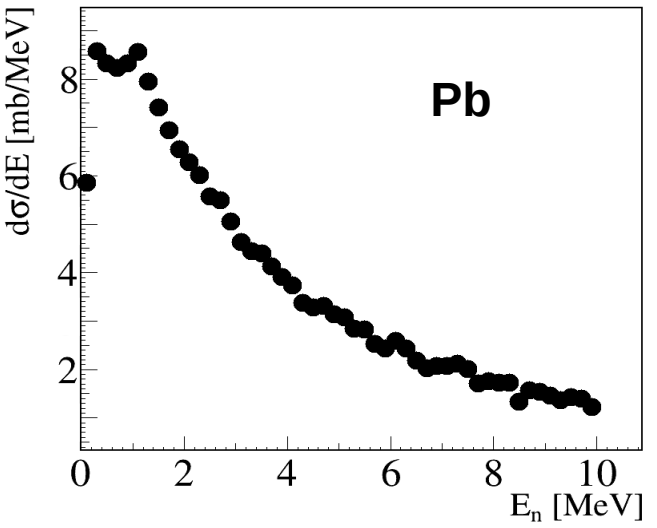
	^{49}Ca (mb)	^{48}Ca (mb)
Pb target	351.7 ± 15.0	274.9 ± 14.0
C target	73.1 ± 2.5	70.9 ± 2.4

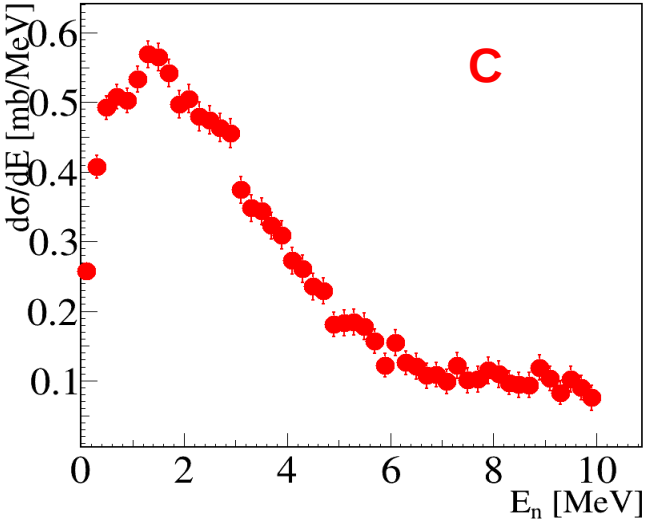


Results: Differential cross section → 49Ca + n

Differential cross sections for 49Ca+n (stat uncertainties only):

- Integral for Pb → 192.9 ± 6.8 mb
- Integral for C → 13.1 ± 0.9 mb





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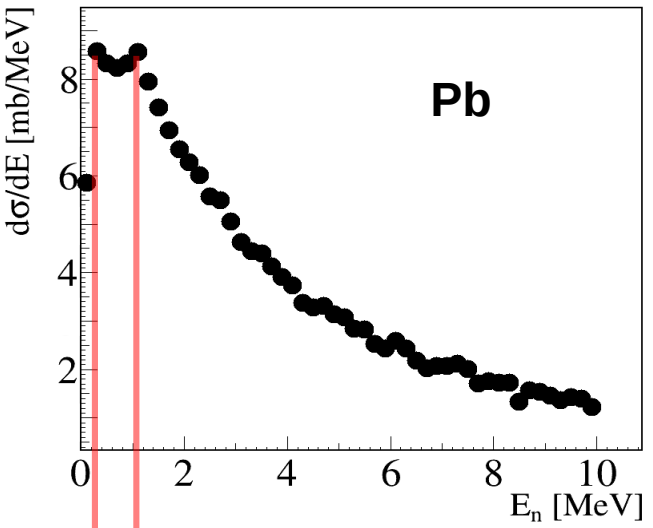
Two sharp peaks for Pb:

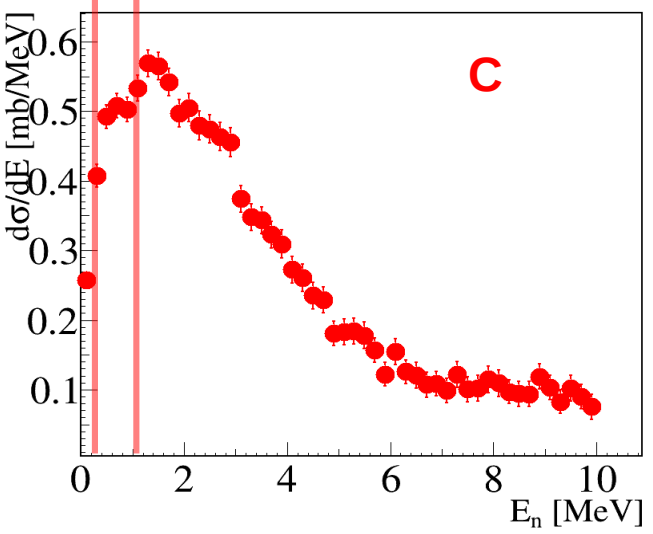
~ 400 keV → Near neutron threshold

~ 1.2 MeV

One peak for C:

~ 1.4 – 1.6 MeV





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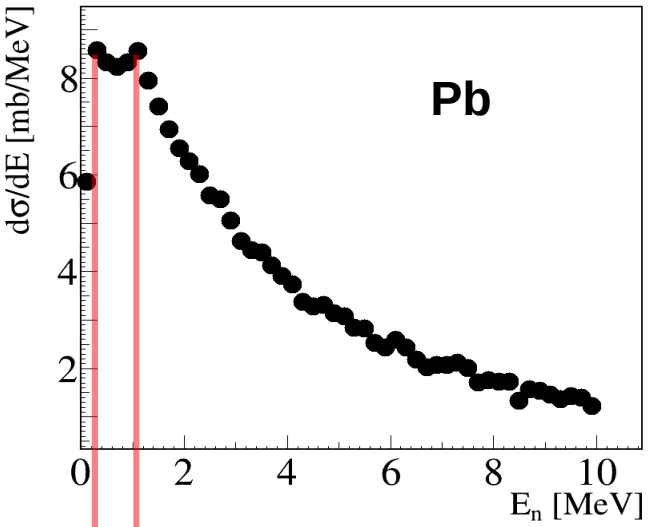
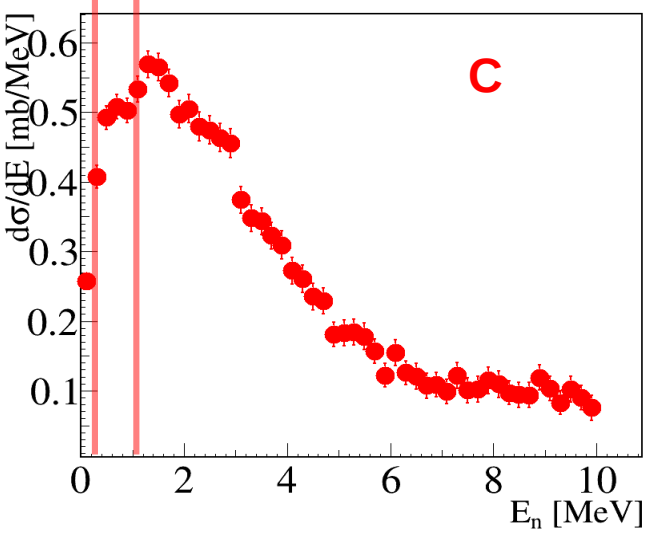
Structure near neutron emission energy threshold
→ Candidate for PDR





Results: Coulomb excitation cross section → 49Ca+n

Nuclear contribution can be determined:

$$\sigma_{CoulEx} = \sigma_{Pn} - \Gamma \sigma_{C}$$

with:

$$\Gamma = \frac{A_{beam}^{1/3} + A_{Pb}^{1./3.}}{A_{beam}^{1/3} + A_{C}^{1/3}} \approx 1.6$$

[K. Boretzky, PRC 68, (2003)]

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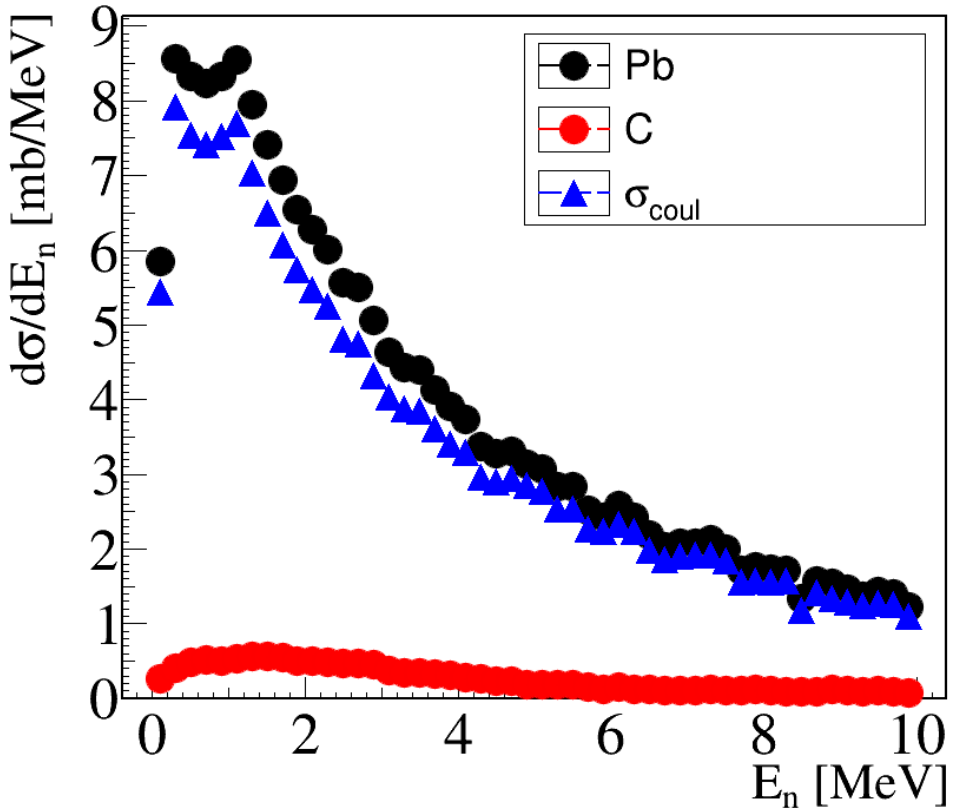
[K. Boretzky, PRC 68, (2003)]

Coulomb excitation cross section:
→ 171.9 ± 6.9 mb



Summary

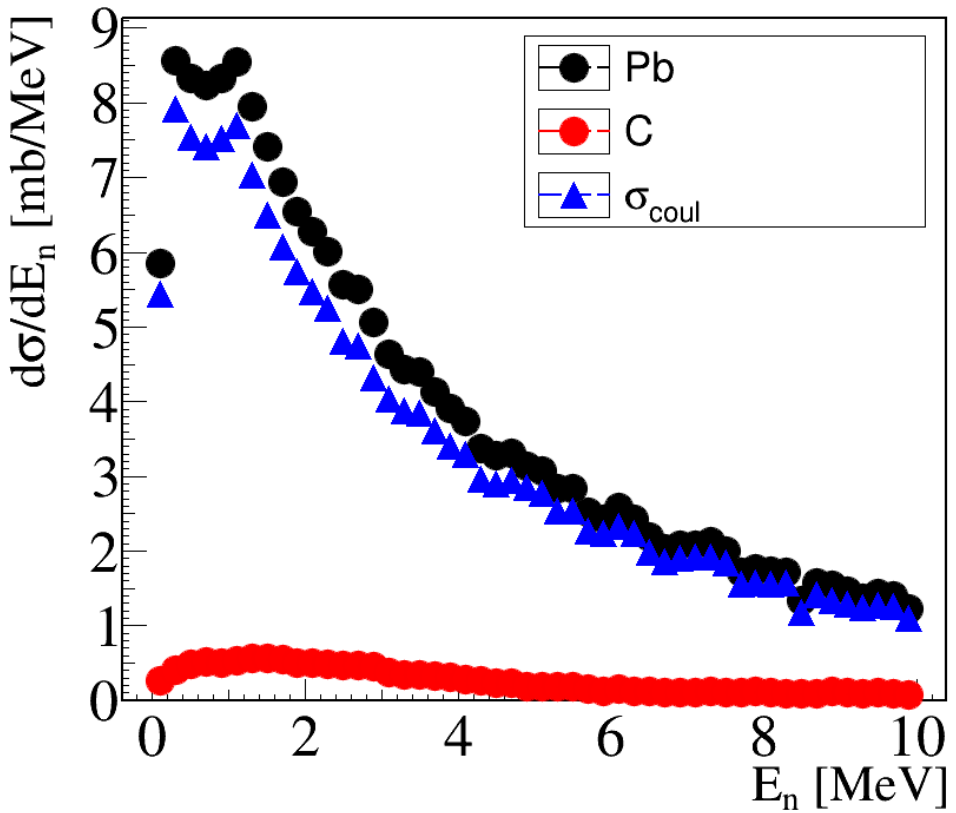
- Shell effect on the PDR for many species

- Coulomb excitation reaction → 50Ca + Pb to probe its Pygmy Dipole Resonance

- Apparent resonances on neutron energy spectrum

- Simulations to determine the response function

→ Determine α_D and compare with ^{52}Ca data



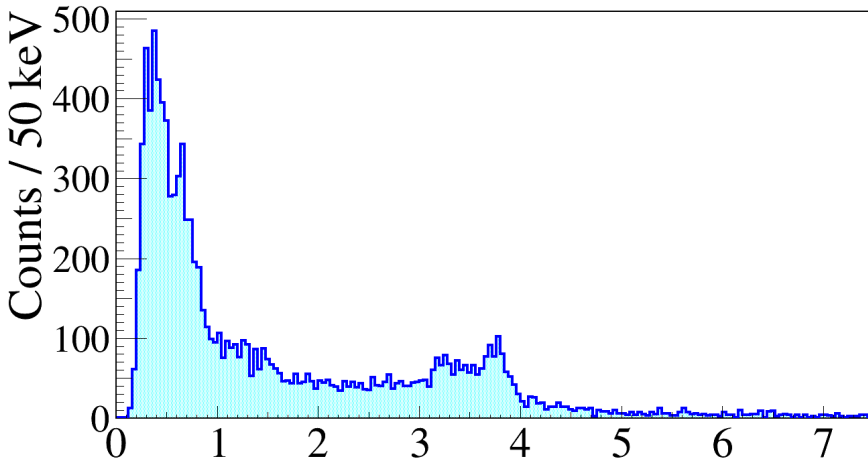
Backup

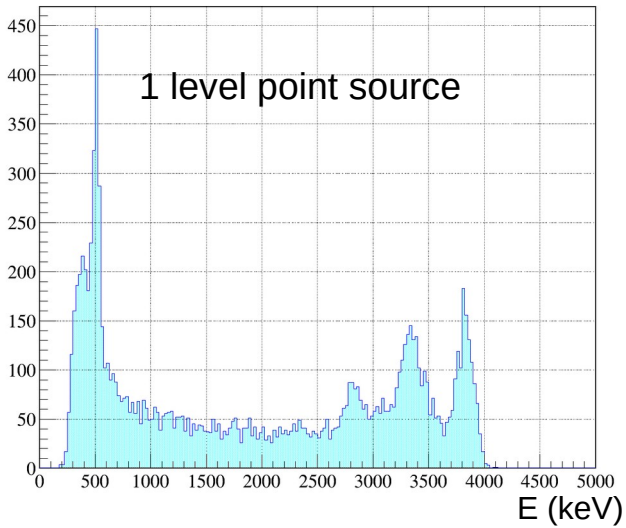
Addback algorithm (48Ca levels)

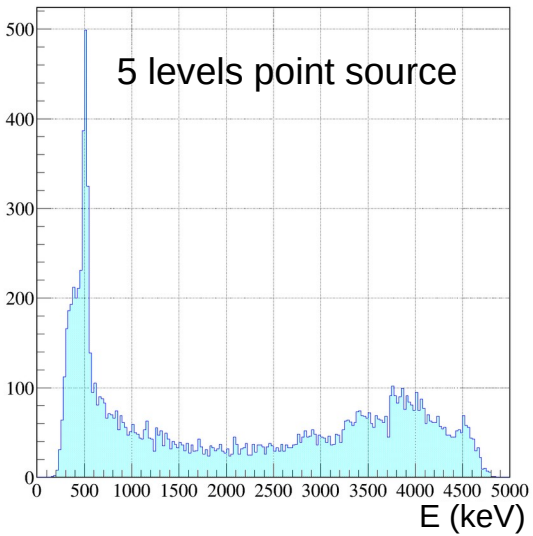
GEANT4 simulation, 1 million events, point source of:

→ First level of 48Ca (3.8MeV)

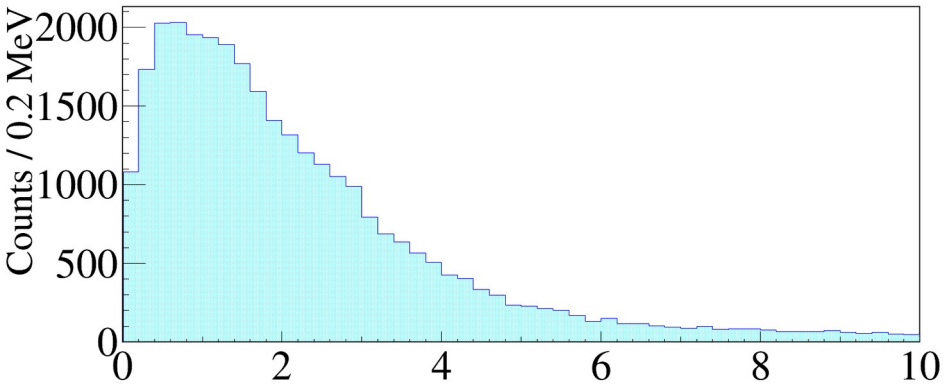
→ First five levels of 48Ca (3.8, 4.3, 4.5, 4.6 MeV)

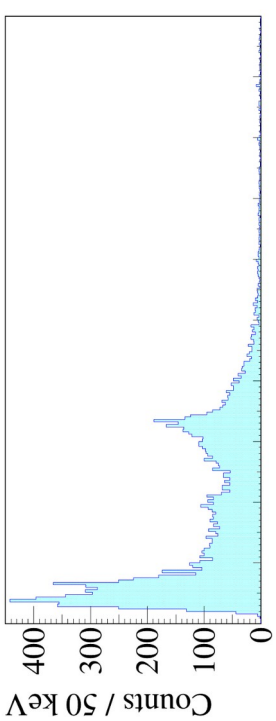


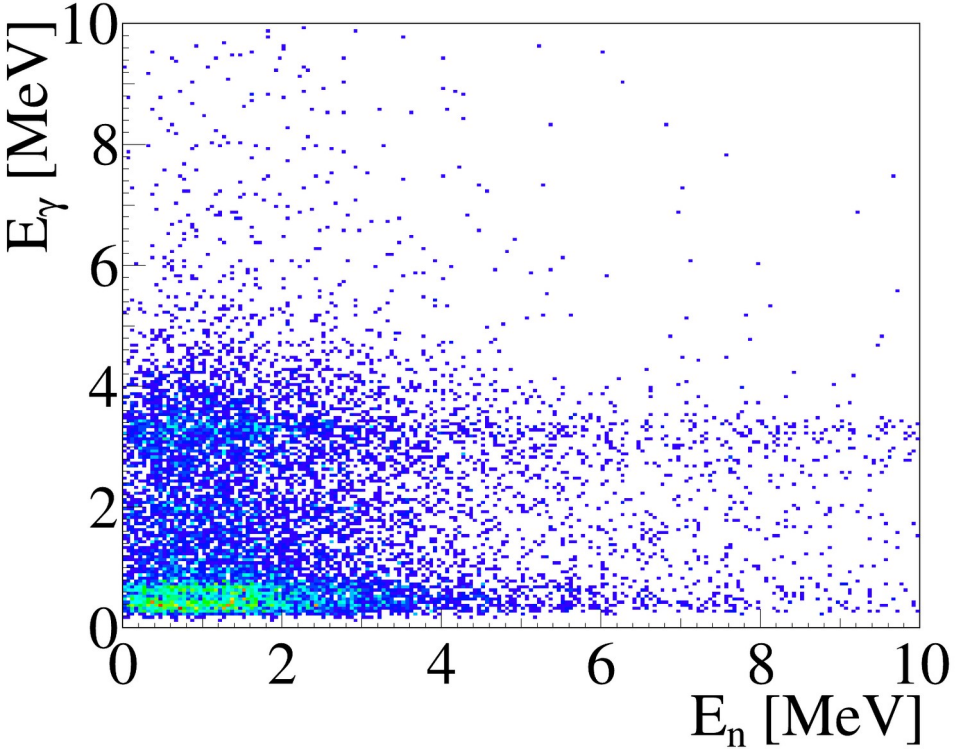




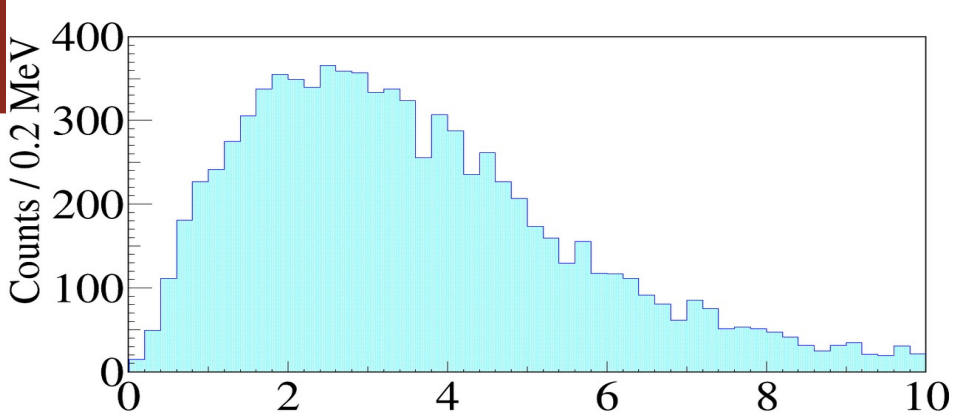
C spectrum 49Ca

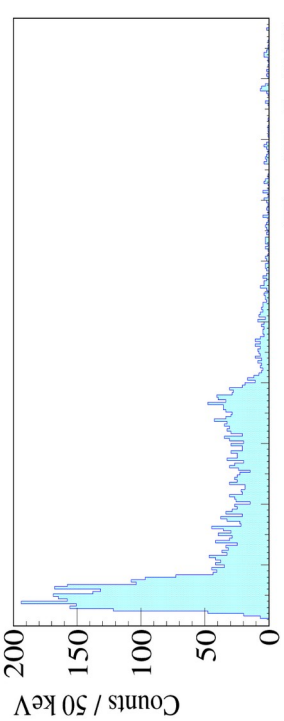


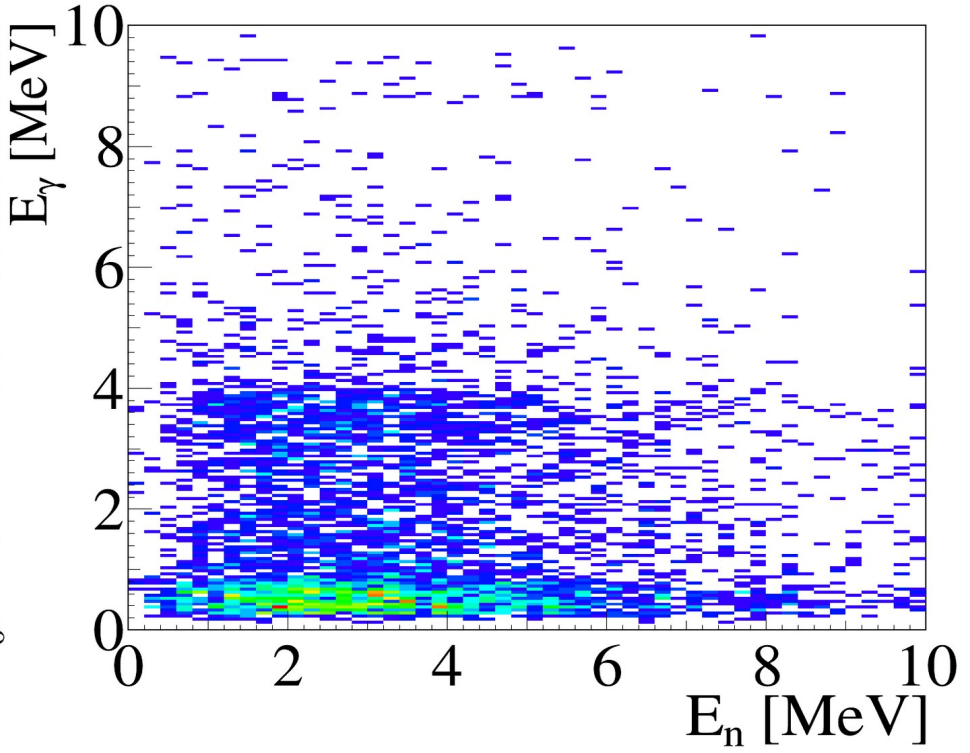


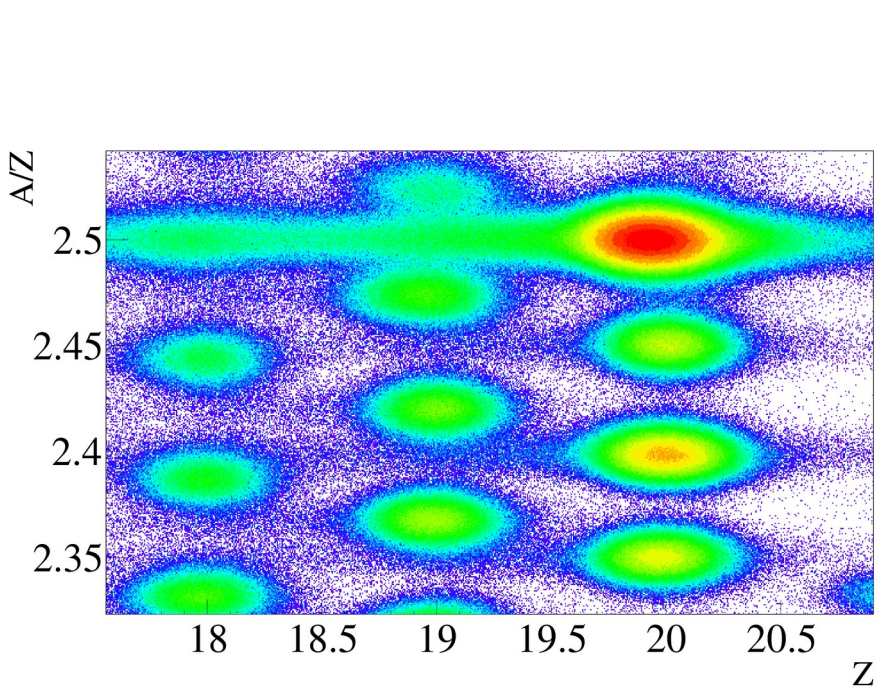


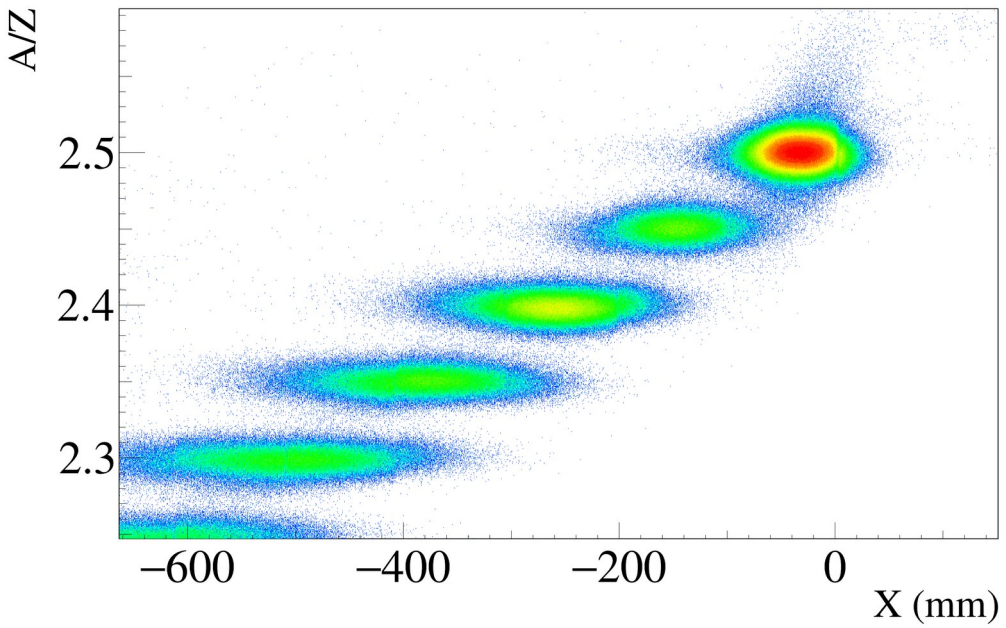
C spectrum 48Ca








A/Z
2.5
2.45
2.4
2.35
18
18.5
19
19.5
20
20.5
Z


A/Z
2.5
2.4
2.3
−600
−400
−200
0
X (mm)