Decay of the PDR in ^{140}Ce. First results from the γ^3 coincidence setup at HIγS

15.01.2014

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GSI Helmholtzzentrum für Schwerionenforschung

Frankfurt Institute for Advanced Studies FIAS

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[3]Institut für Kernphysik, Universität zu Köln, Köln

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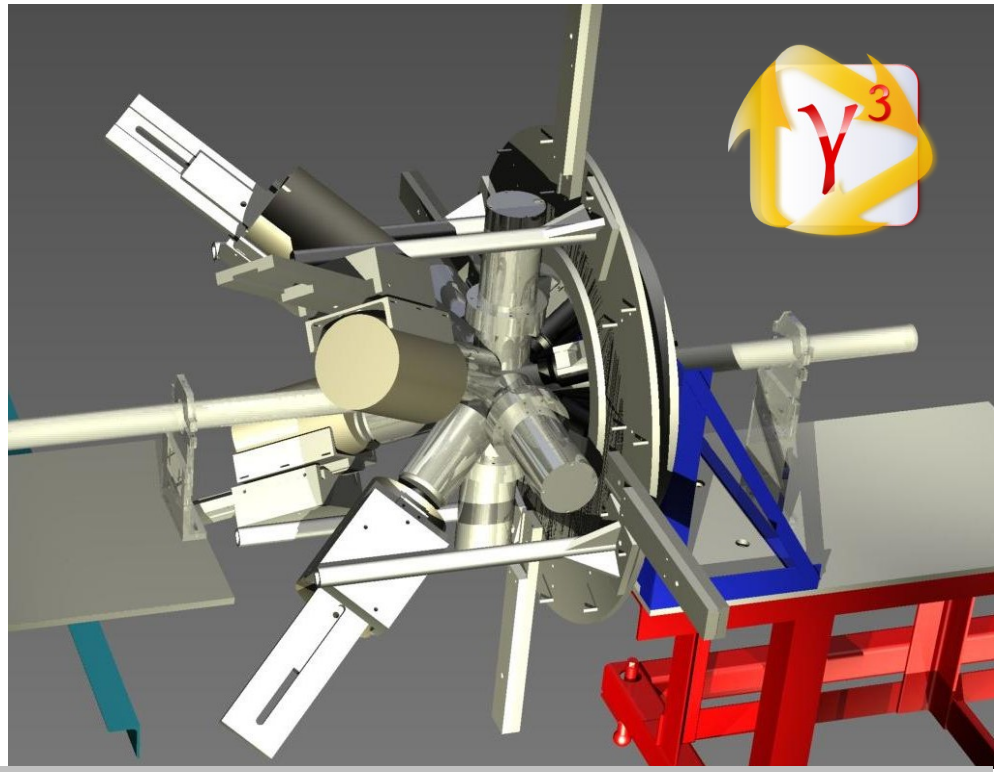

HGS-HIRe for FAIR
Helmholtz Graduate School for Hadron and Ion Research

FIAS Frankfurt Institute for Advanced Studies

Motivation

New experimental possibilities at γ^3 to study decay patterns

- Study of the Pygmy Dipole Resonance
- Deeper Investigation of the Scissors Mode
- Two phonon excitations in light and heavy nuclei

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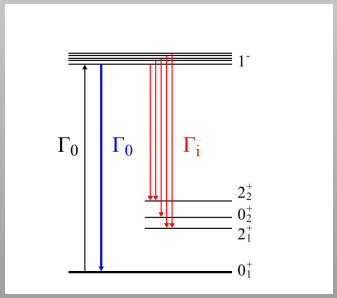
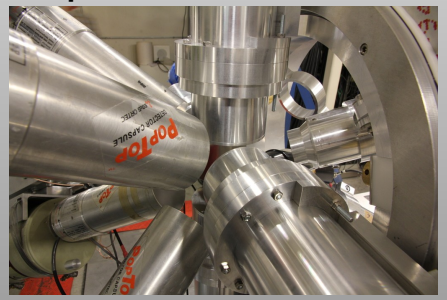
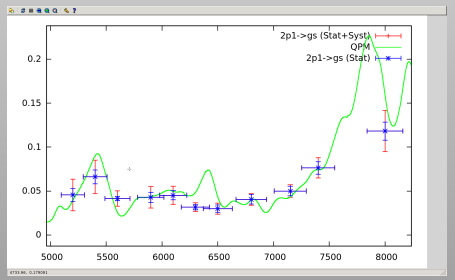
Introduction



Experiment



Results



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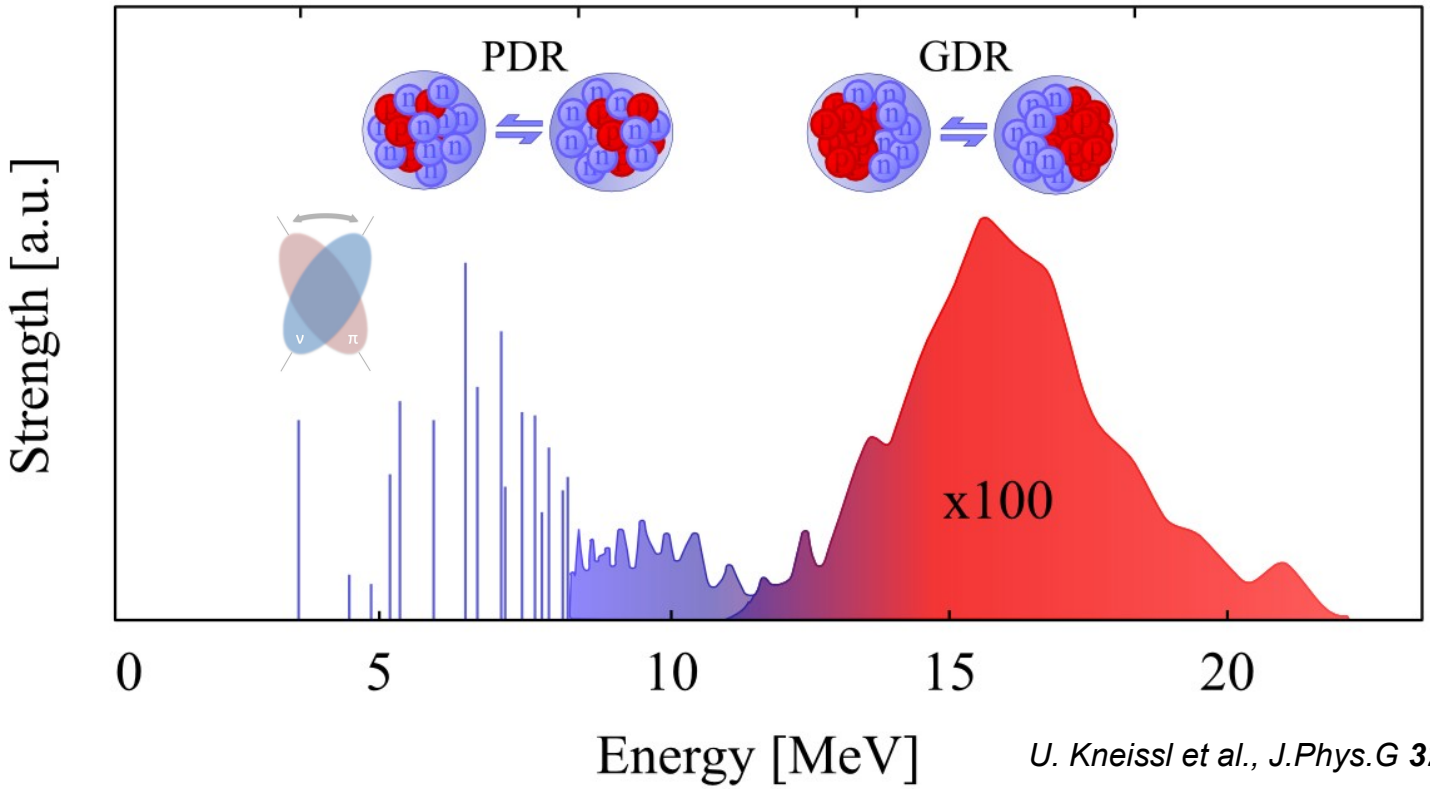
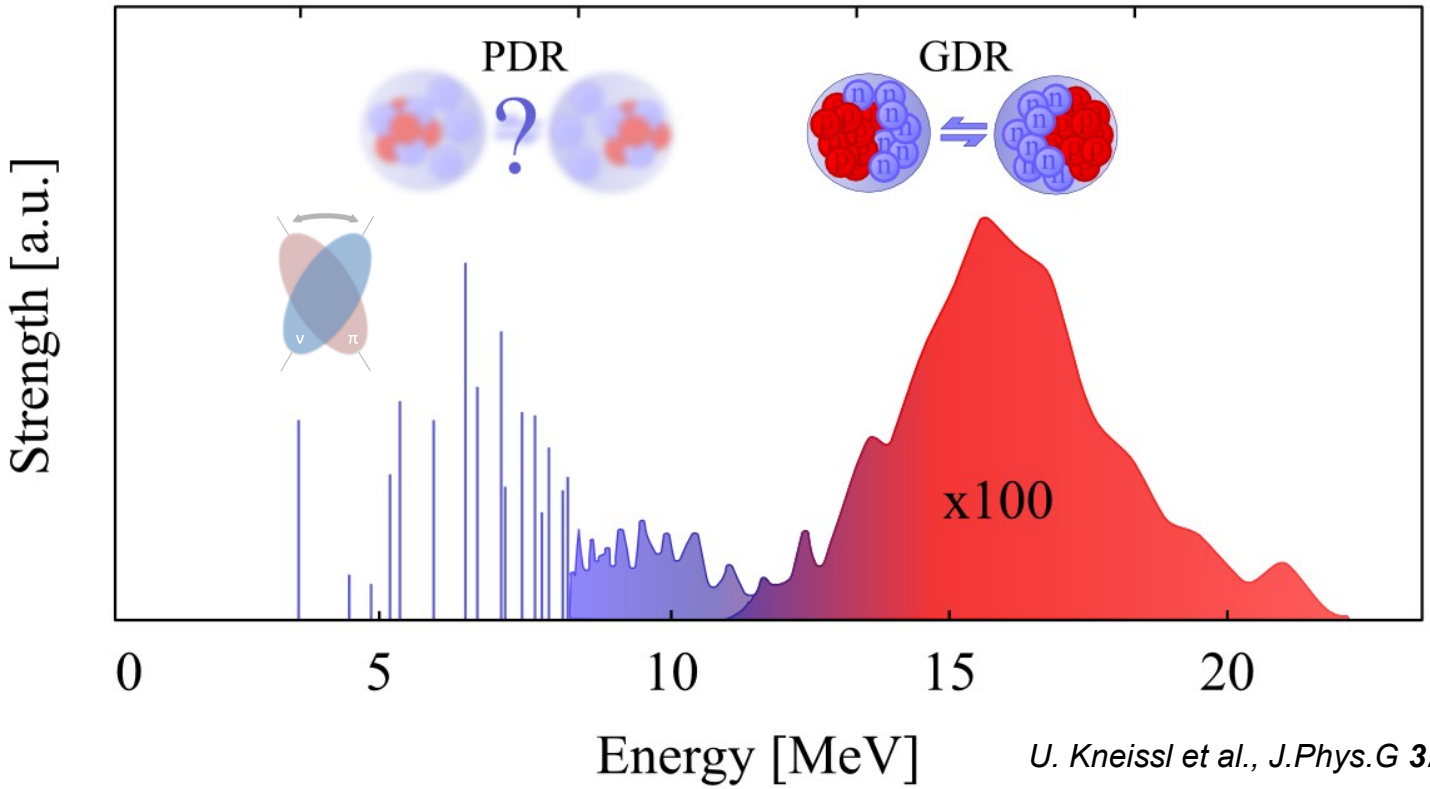


*U. Kneissl et al., J.Phys.G **32**, R217 (2006)*

Dipole Photoresponse of (spherical) nuclei

- M1 Scissor's Mode
- GDR: Oscillation of Neutrons vs. Protons
- PDR: Oscillation of Neutron skin vs. Core

Motivation



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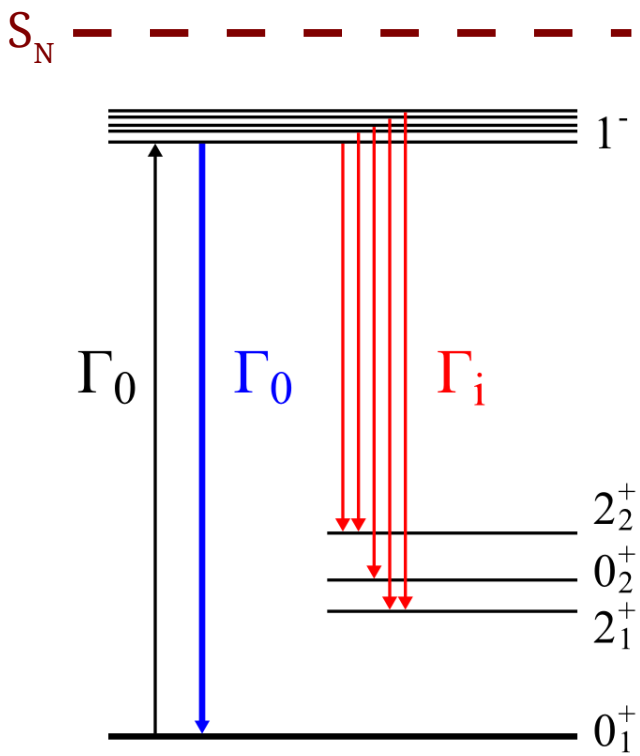
Experimental Method

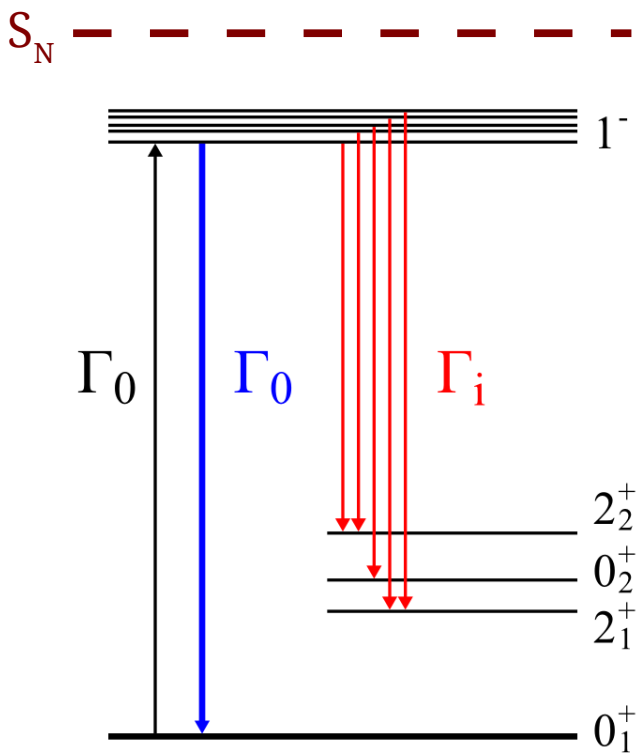


- Decay „elastic“ (Γ_0) or „inelastic“ (Γ_i)
- Elastic channel dominant: ($\Gamma_0 \gg \Gamma_i$)

Nuclear Resonance Fluorescence (NRF)

X(γ,γ')X

Experimental Method

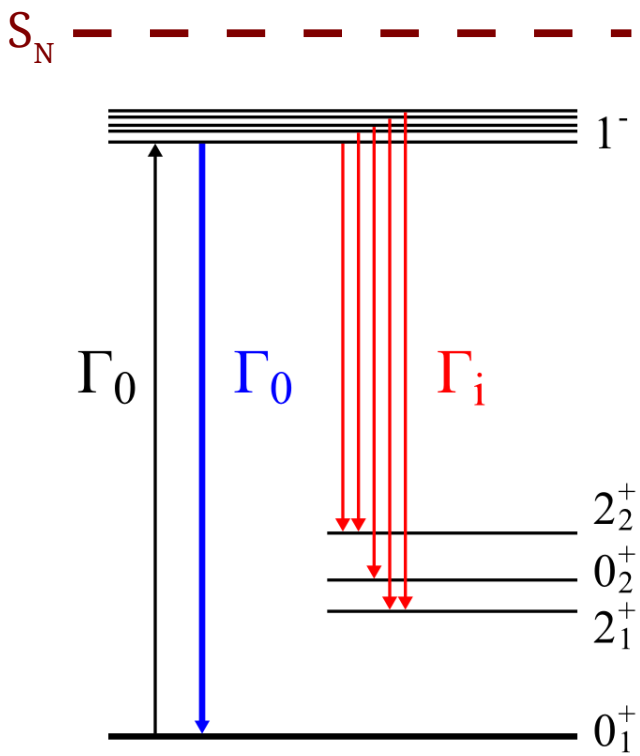


- Decay „elastic“ (Γ_0) or „inelastic“ (Γ_i)
- Elastic channel dominant: ($\Gamma_0 \gg \Gamma_i$)

Usually in NRF assume $\Gamma_0/\Gamma \approx 1$

→ This may not be the case for the $\sum_i \Gamma_i$!

Experimental Method

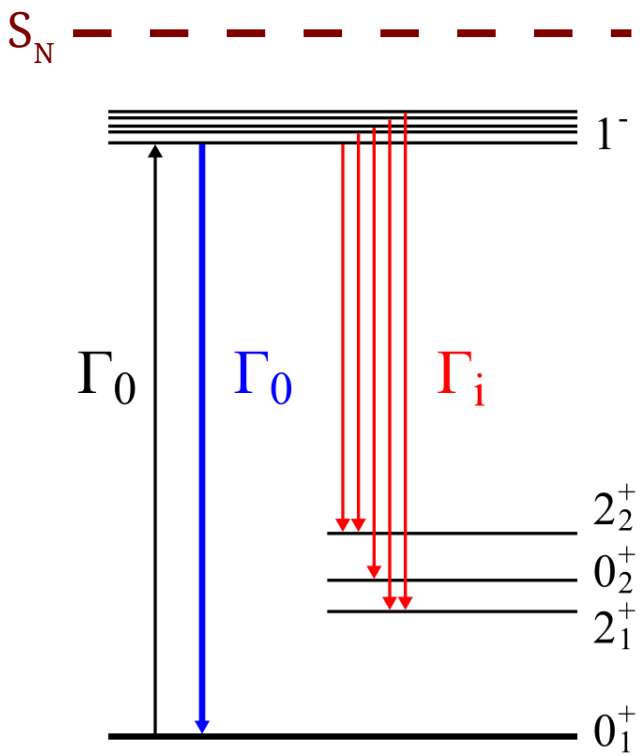


- Decay „elastic“ (Γ_0) or „inelastic“ (Γ_i)
- Elastic channel dominant: ($\Gamma_0 \gg \Gamma_i$)

To determine Decay Pattern, Γ_i need to be determined

→ Challenge: Measure small branching ratios $b_0 = \frac{\Gamma_i}{\Gamma}$

Experimental Method



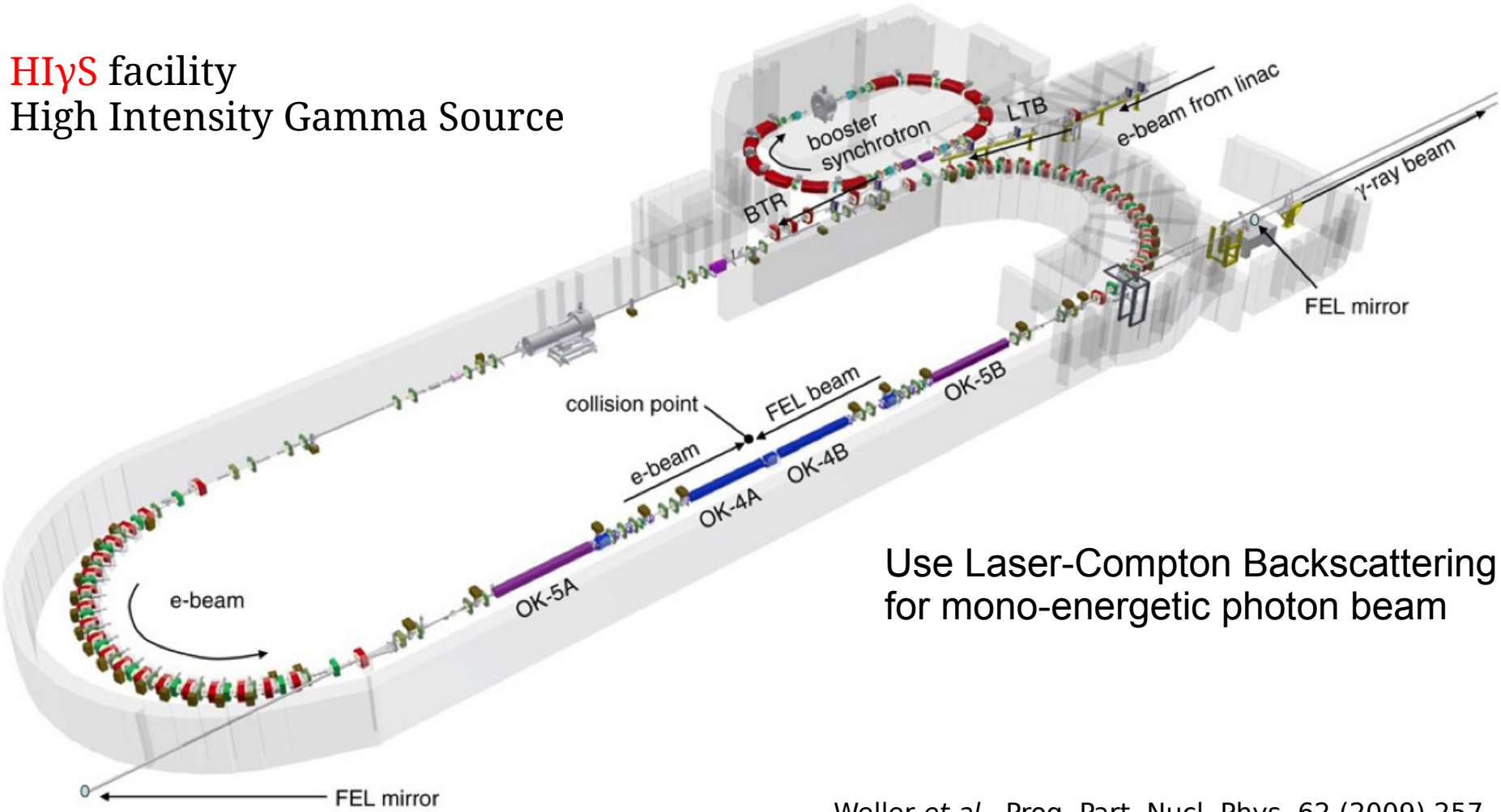
- Decay „elastic“ (Γ_0) or „inelastic“ (Γ_i)
- Elastic channel dominant: ($\Gamma_0 \gg \Gamma_i$)

Use:

- Selectivity of NRF reaction → Mostly J=1 states

Experimental Method

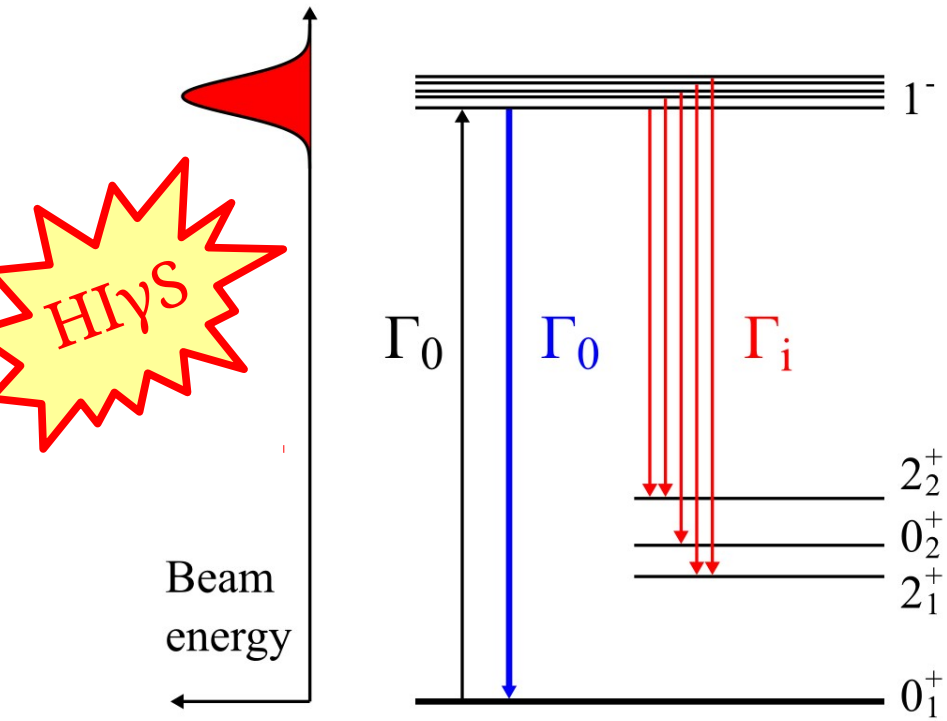
HIγS facility
High Intensity Gamma Source



Use Laser-Compton Backscattering for mono-energetic photon beam

Weller *et al.*, Prog. Part. Nucl. Phys. 62 (2009) 257

Experimental Method

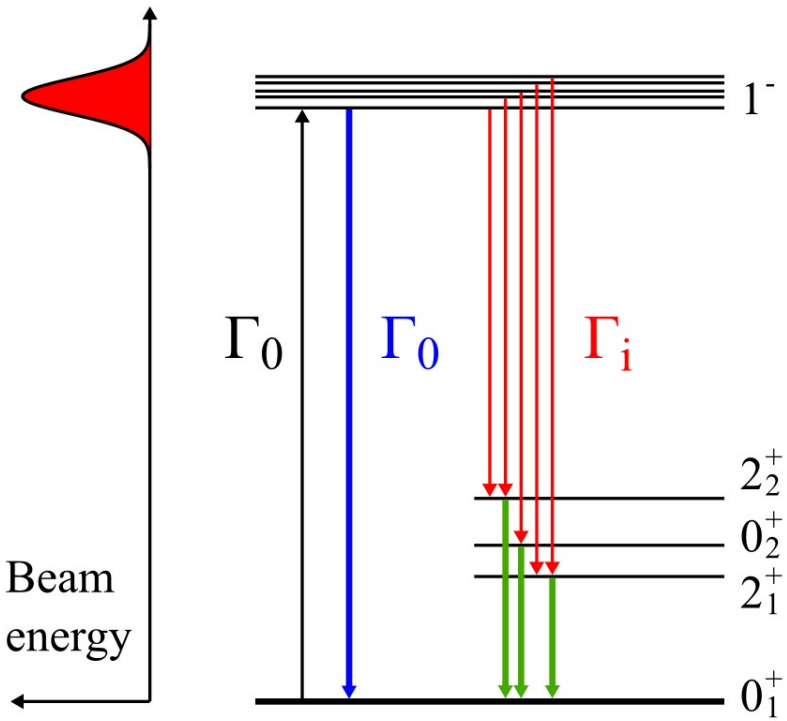


- Decay „elastic“ (Γ_0) or „inelastic“ (Γ_i)
- Elastic channel dominant: ($\Gamma_0 \gg \Gamma_i$)

Use:

- Selectivity of NRF reaction and mono-energetic beam
  → Prepare nucleus in well-defined excitation mode

Experimental Method

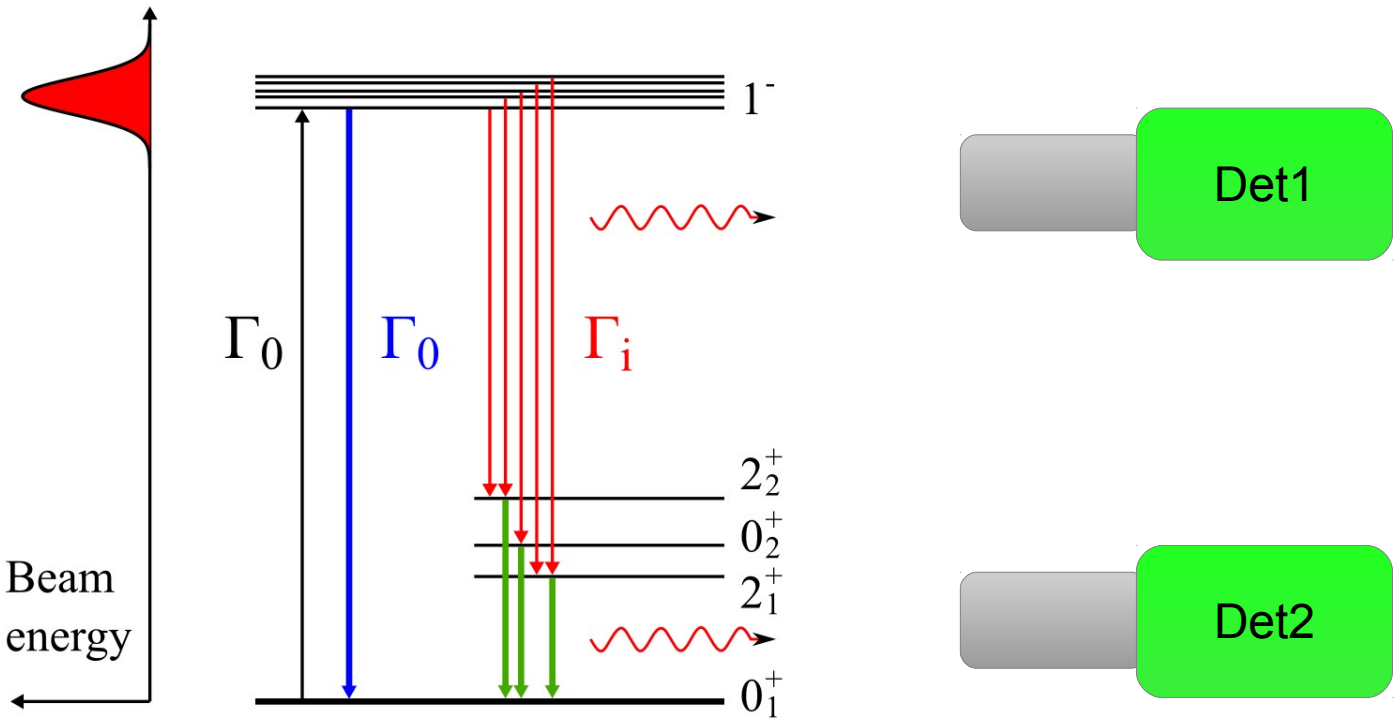


- Decay „elastic“ (Γ_0) or „inelastic“ (Γ_i)
- Elastic channel dominant: ($\Gamma_0 \gg \Gamma_i$)
- Select low energy decay

Combine:

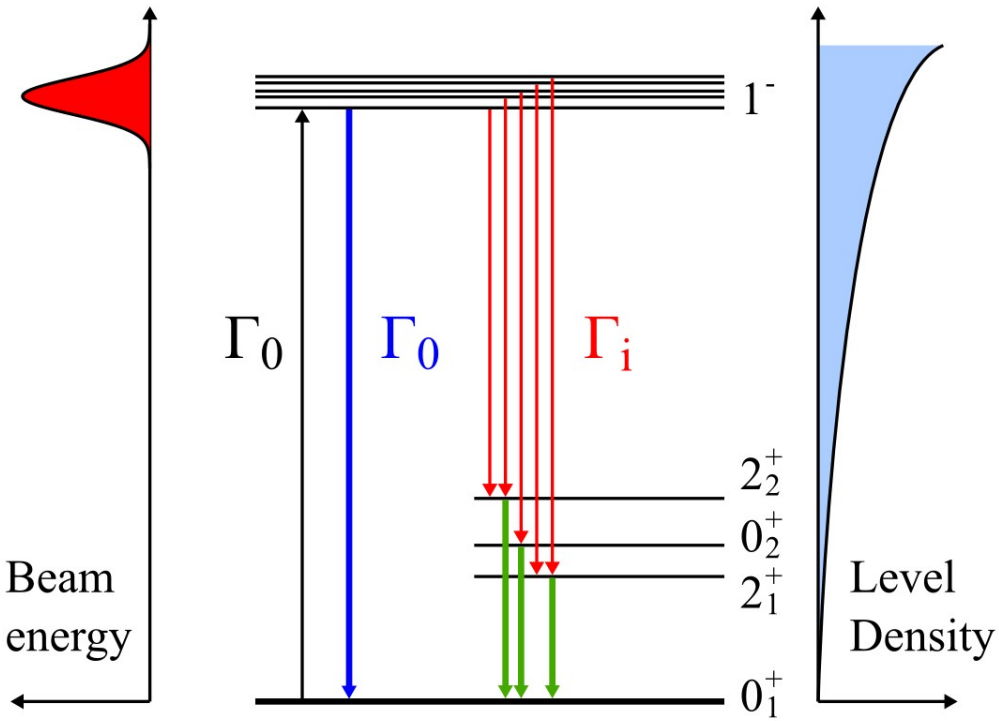
- Selectivity of NRF reaction and mono-energetic beam
- Sensitivity of γ-γ coincidence method

The γ^3 setup



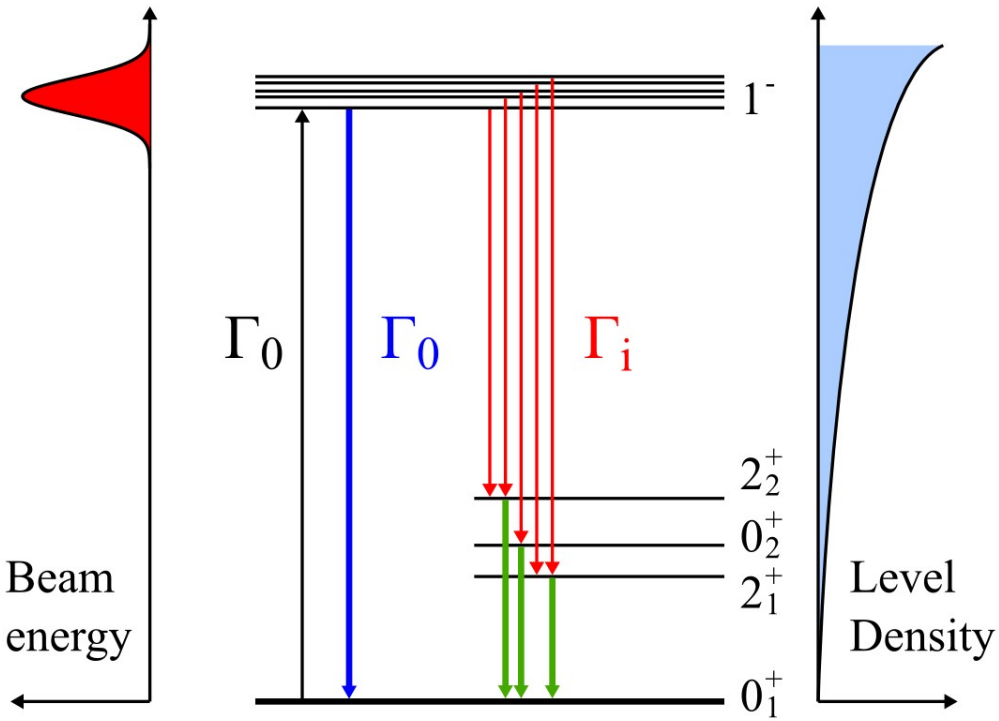
- Detect two photons in coincidence
  → **High photo peak efficiency** needed

The γ^3 setup



High level density
→ Use high resolution HPGe

The γ^3 setup



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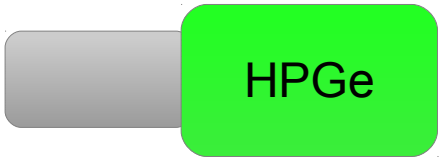
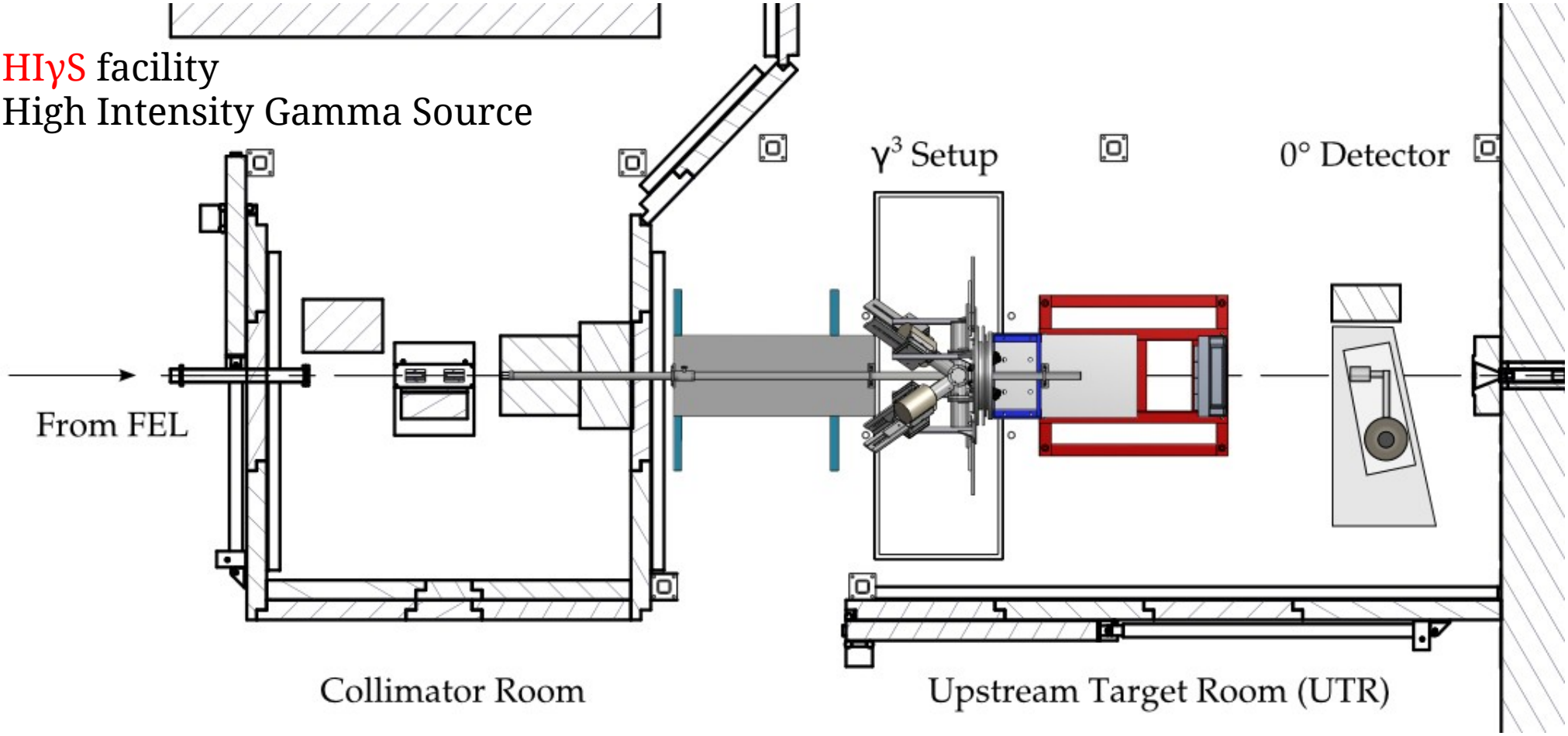


Low level density
→ Use high efficiency LaBr

- Combine HPGe with LaBr detectors

The γ^3 setup

HIγS facility
High Intensity Gamma Source



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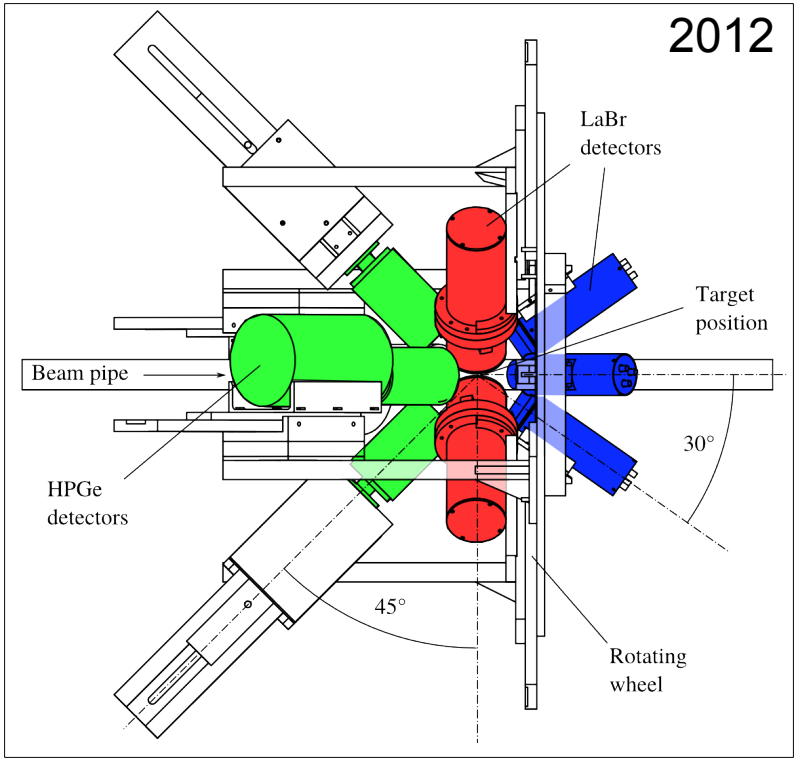

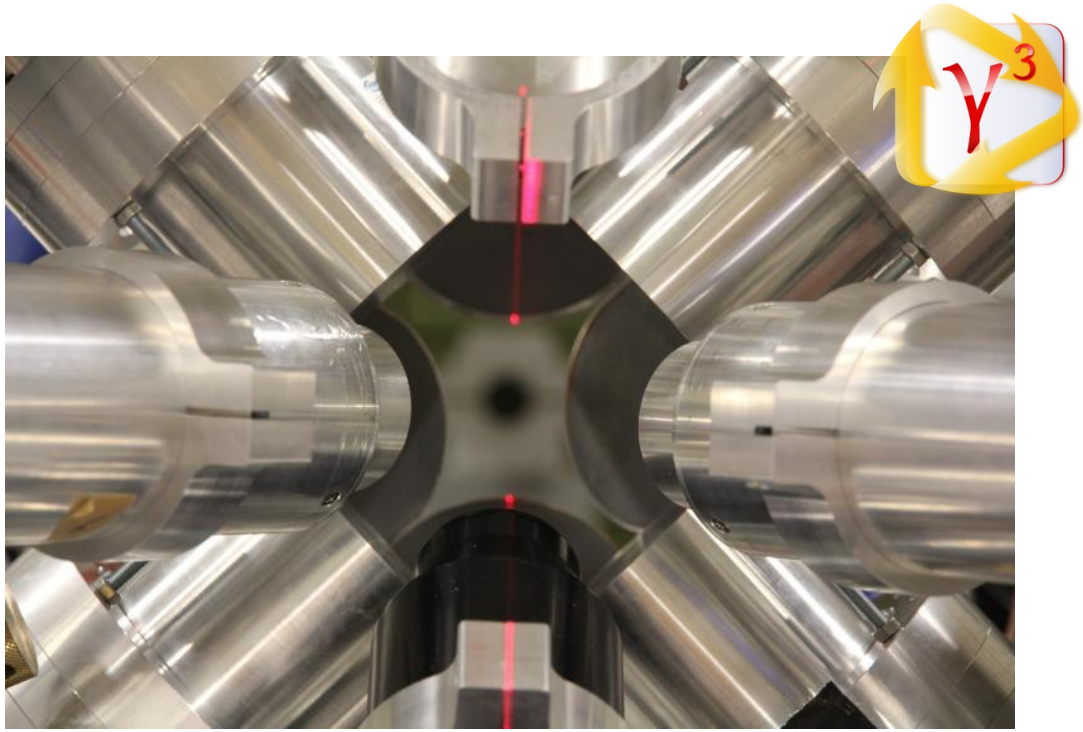

B. Löher et al., Nucl. Instruments Methods Phys. Res. Sect. A **723**, 136–142 (2013).

New detector array at HIγS

- 4 high resolution HPGe detectors
- 7 high efficiency LaBr detectors

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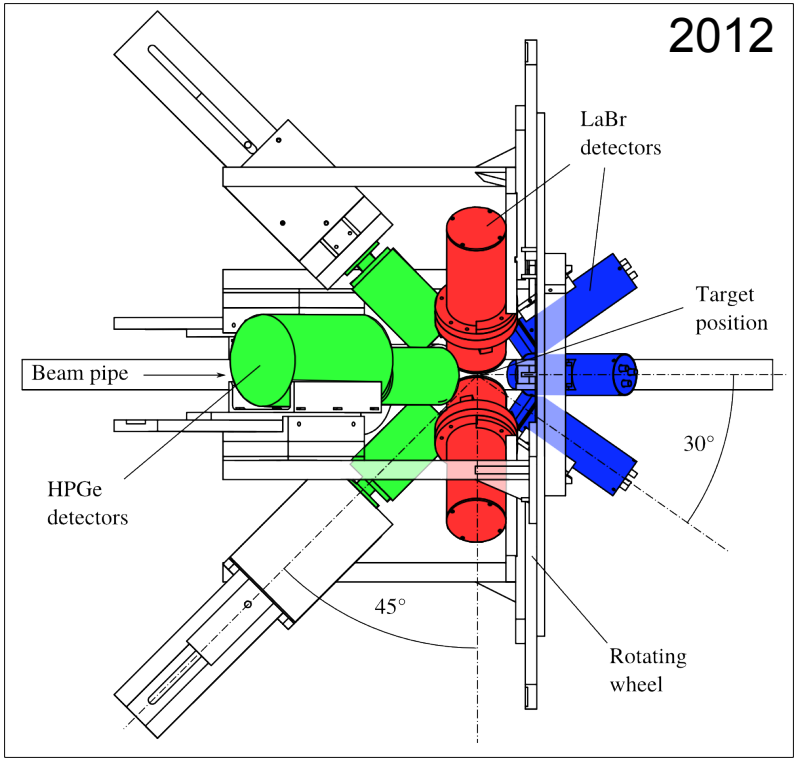

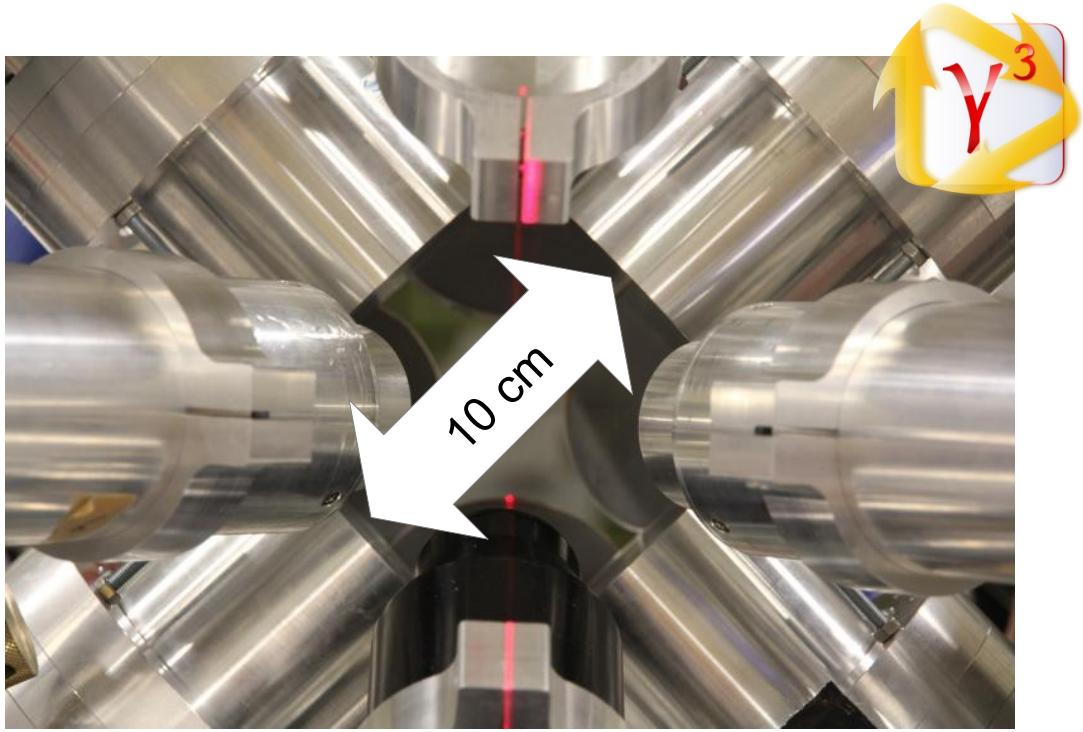

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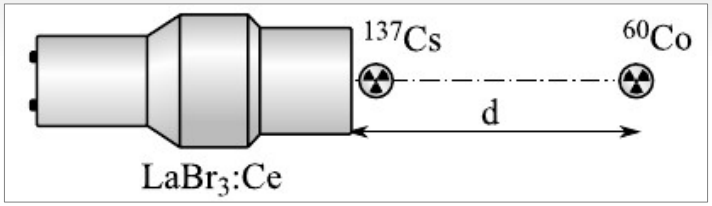
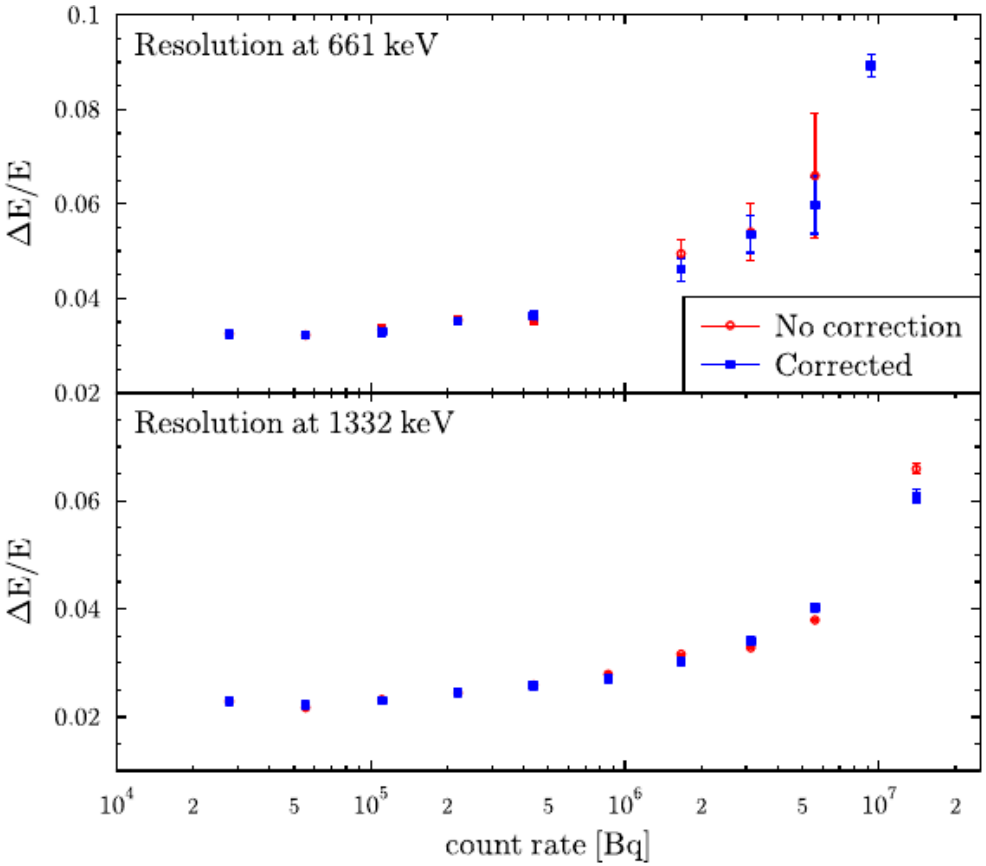
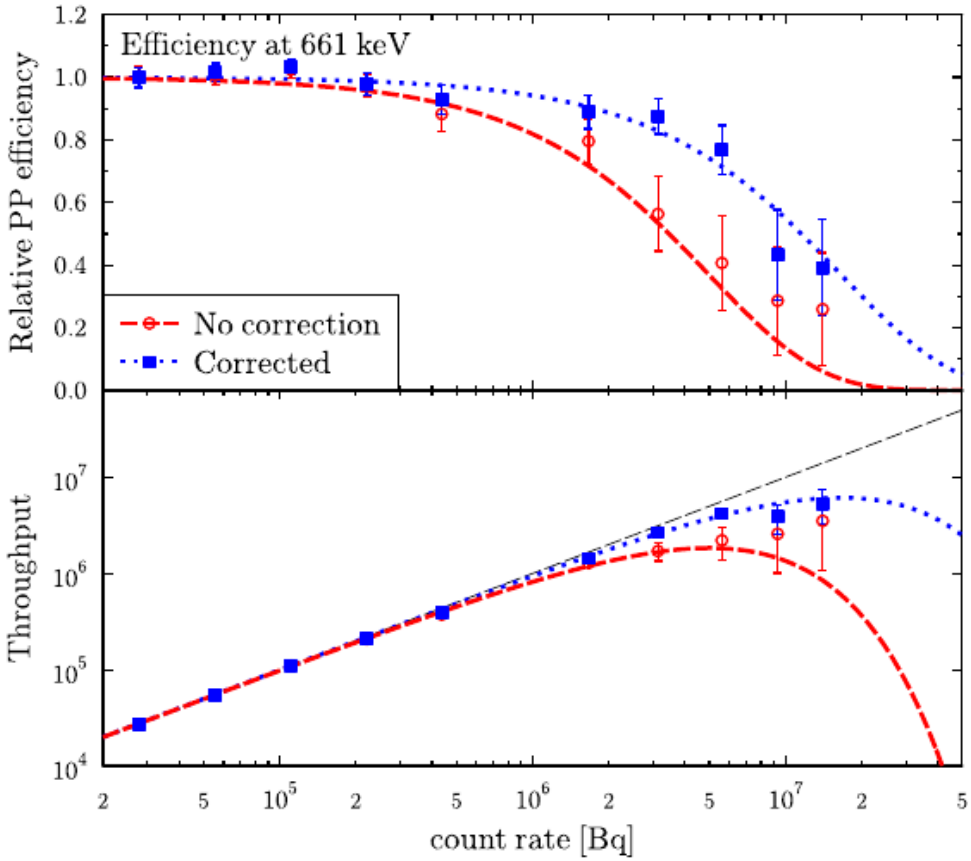


High Count Rate measurement

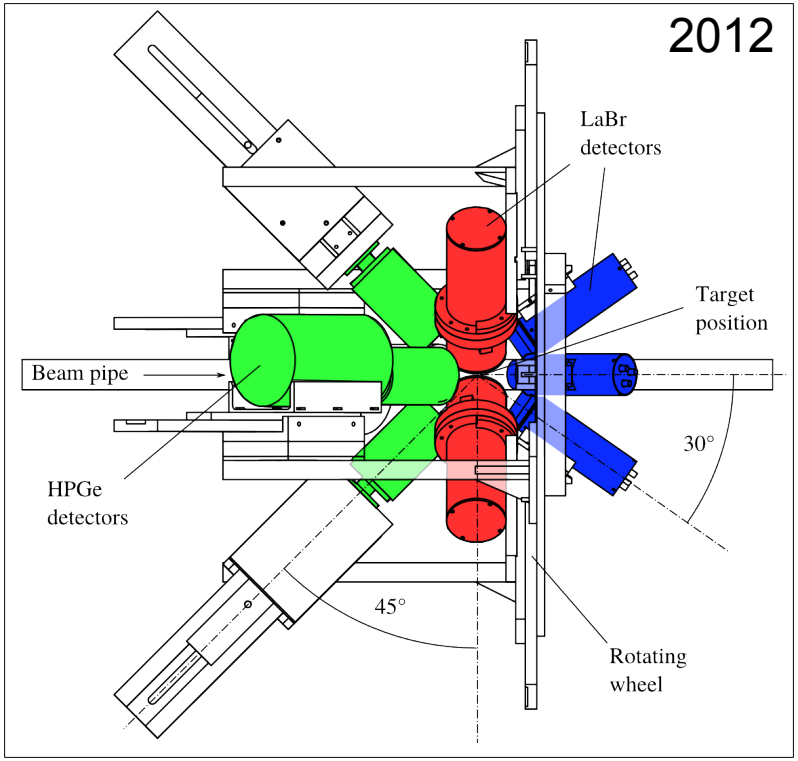




- Count rate at γ^3: LaBr < 300 kHz, HPGe < 20 kHz

B. Löher et al., Nucl. Instruments Methods Phys. A **686** (2012).

The γ^3 setup



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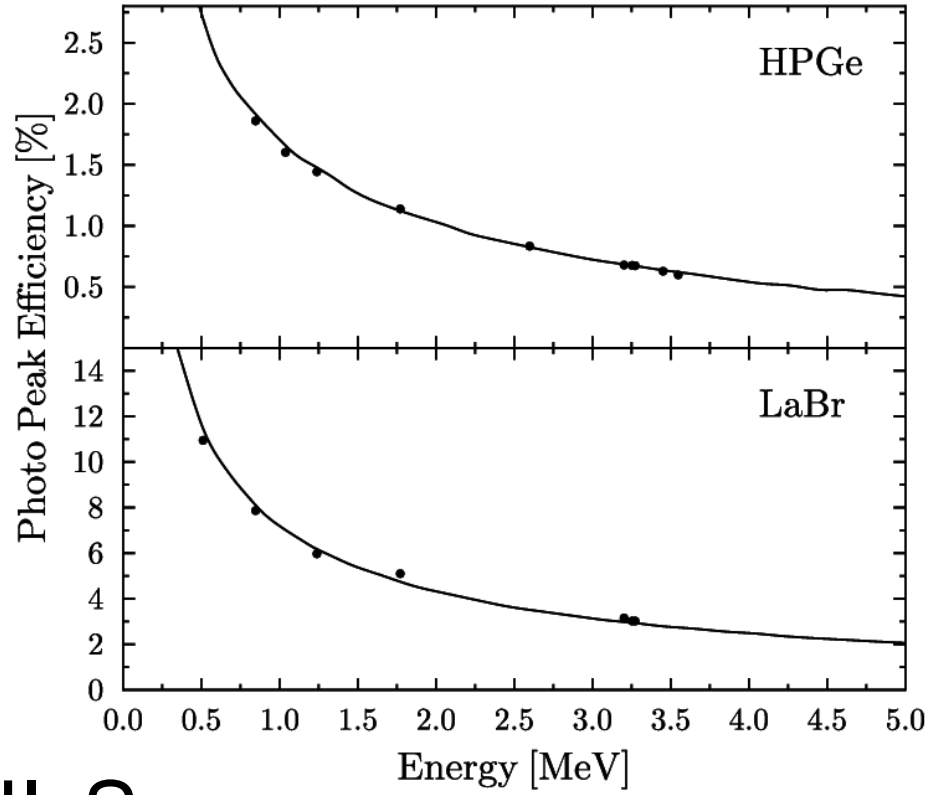
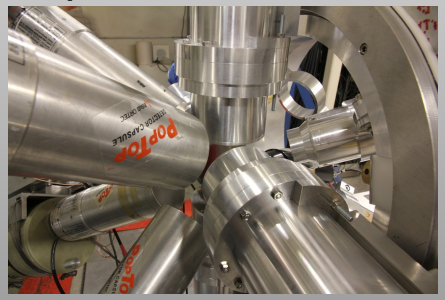


New detector array at HIγS

- Total efficiency: 6% + 1.3% @ 1.3 MeV (LaBr+HPGe)

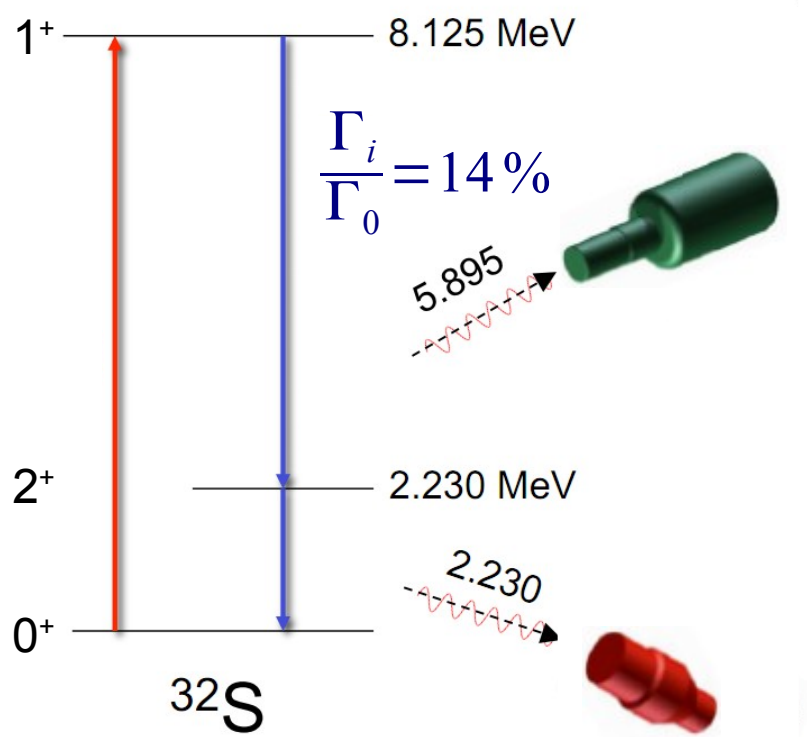
Experiments

Experiment



- Commissioning phase 2012 (^{32}S)
- Experimental Campaign 2012
- Experimental Campaign 2013

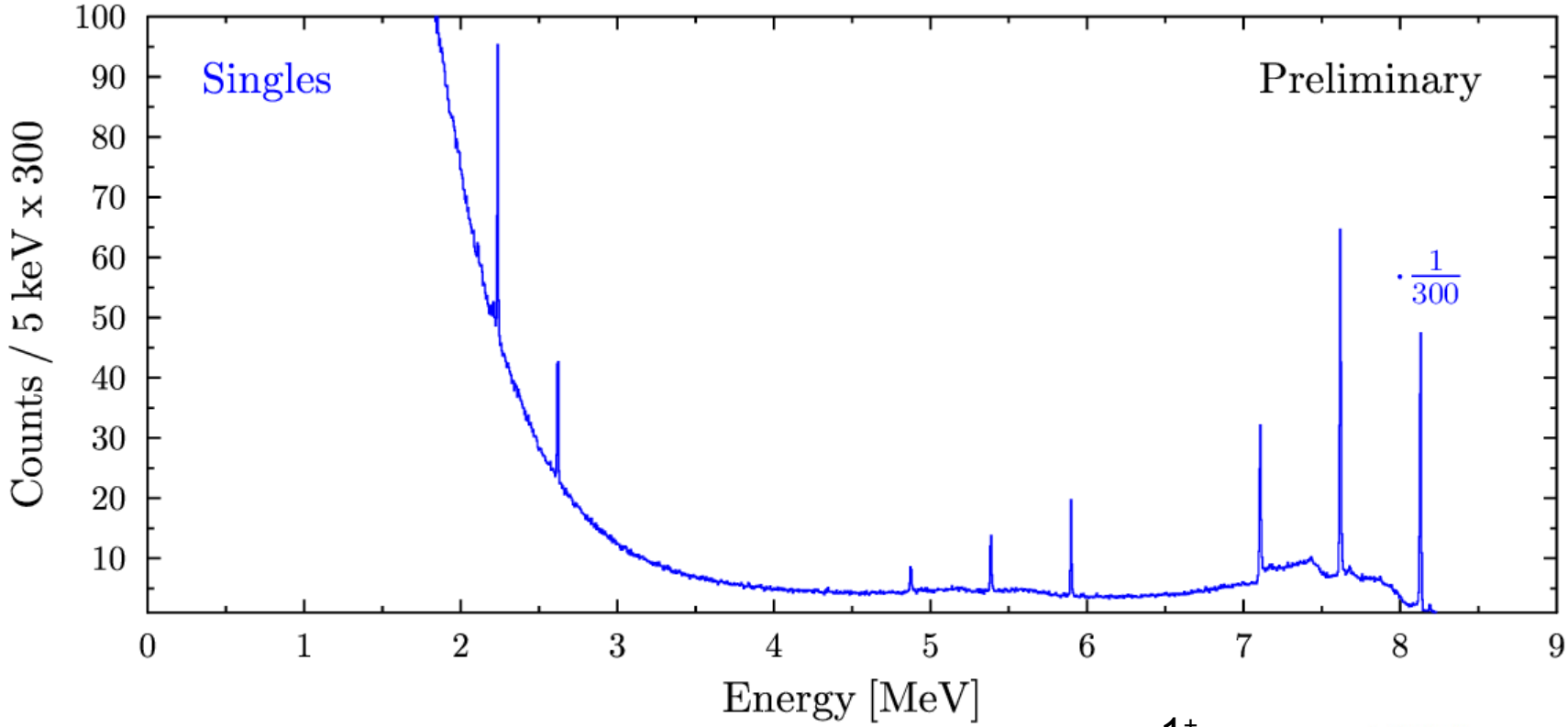
Setup Commissioning

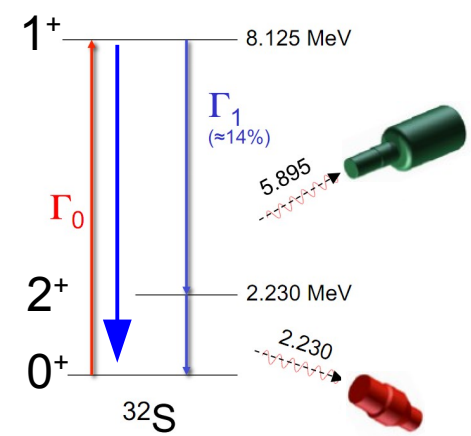


Detectors: 4x HPGe (60%) + 4x 3“x3“ LaBr

- Target: ^{32}S @ 8.125 MeV beam energy
- Beam on Target: 4 h

Setup Commissioning





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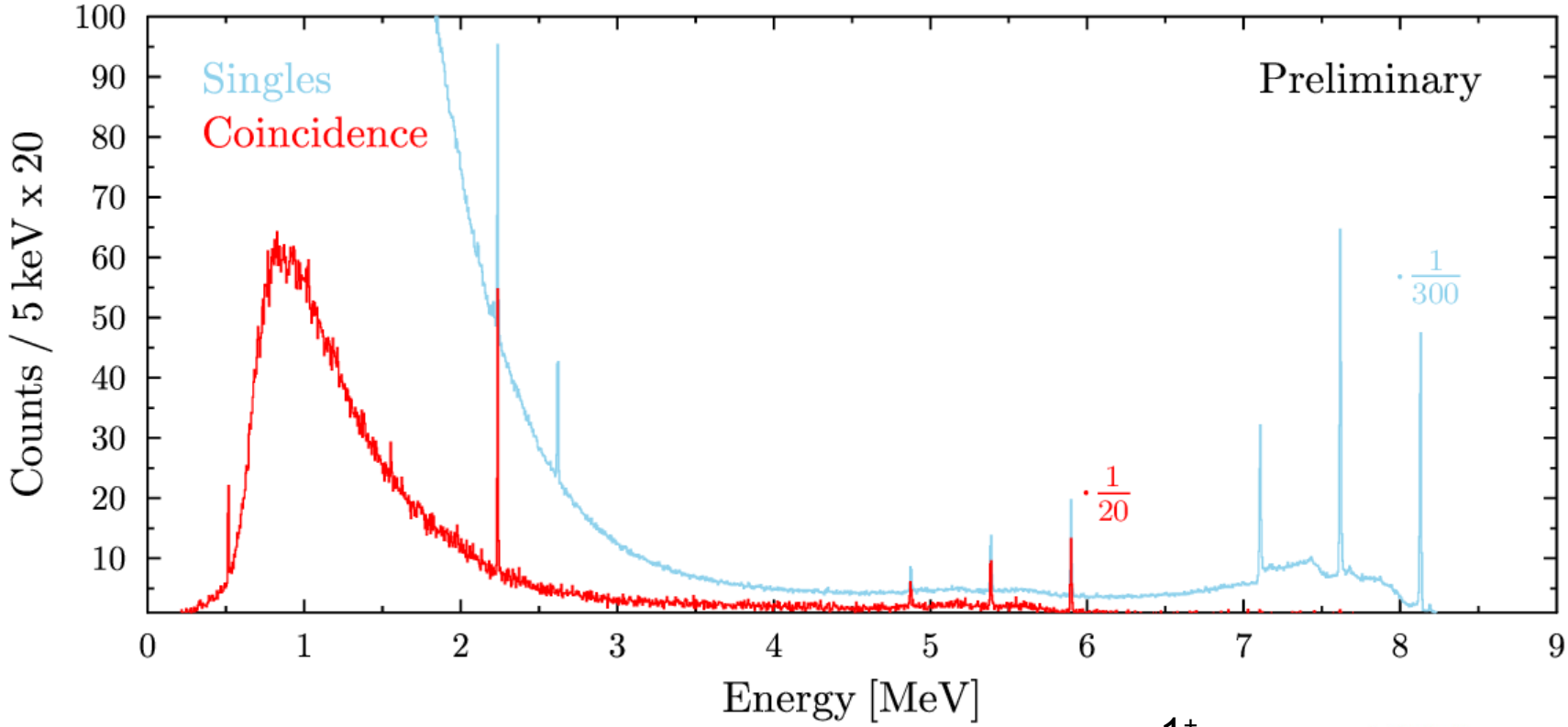

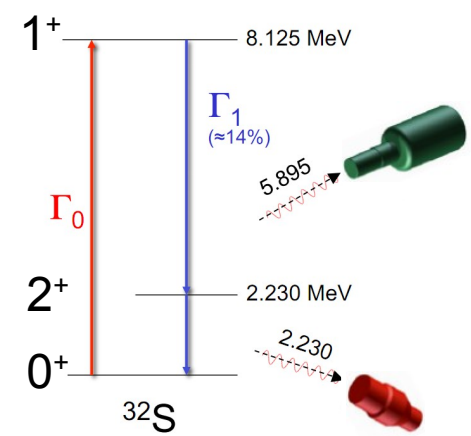

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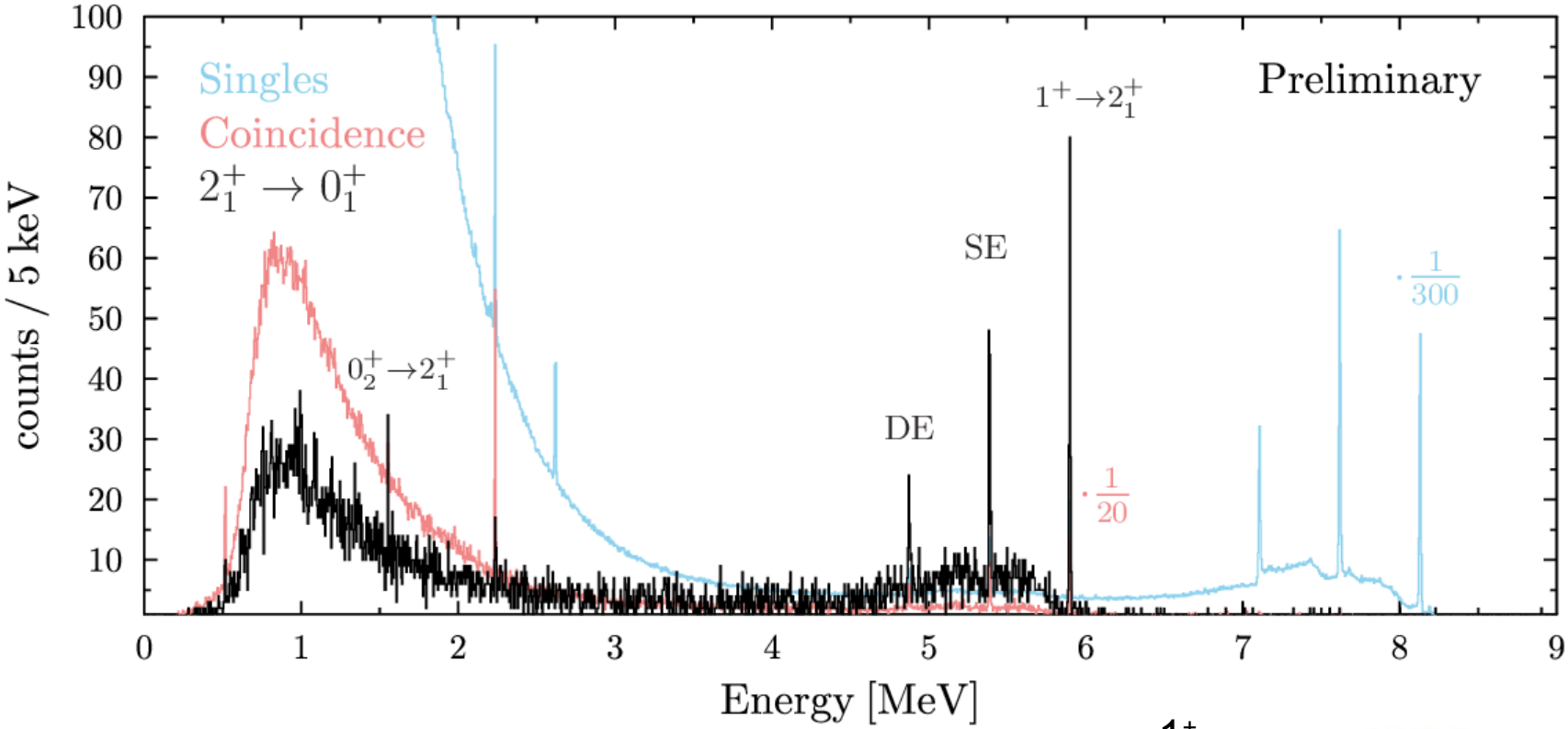
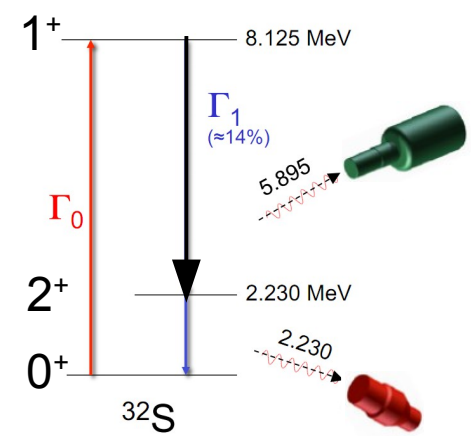


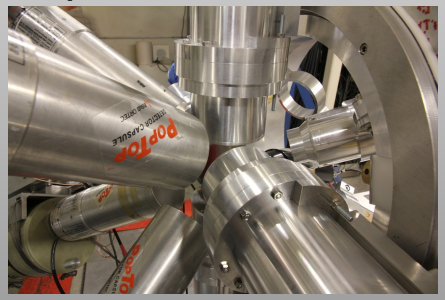
Peak to Background:

2230 keV	• Singles:	0.197(3)
	• Energy Cut:	9.6(15)
5894 keV	• Singles:	1.03(2)
	• Energy Cut:	11.7(13)



Experiments

Experiment



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Experiments

Beam time 2012:

- 700 h of beam time in 5+1 weeks
- Investigated 7+3 nuclei:
- ^{124}Sn, ^{140}Ce, ^{76}Ge, ^{40}Ca, ^{156}Gd + ^{240}Pu, ^{233}U, ^{32}S

Beam time 2013:

- >700 h of beam time in 8 weeks
- Investigated 9+2 nuclei:
  - ^{128}Te, ^{152,156}Gd, ^{140}Ce, ^{92,94}Zr, ^{206}Pb, ^{162,164}Dy + ^{11}B, ^{32}S

Goals:

- Parities, Decay of Scissors Mode and PDR, Measurement of the PSF, 2 phonon state

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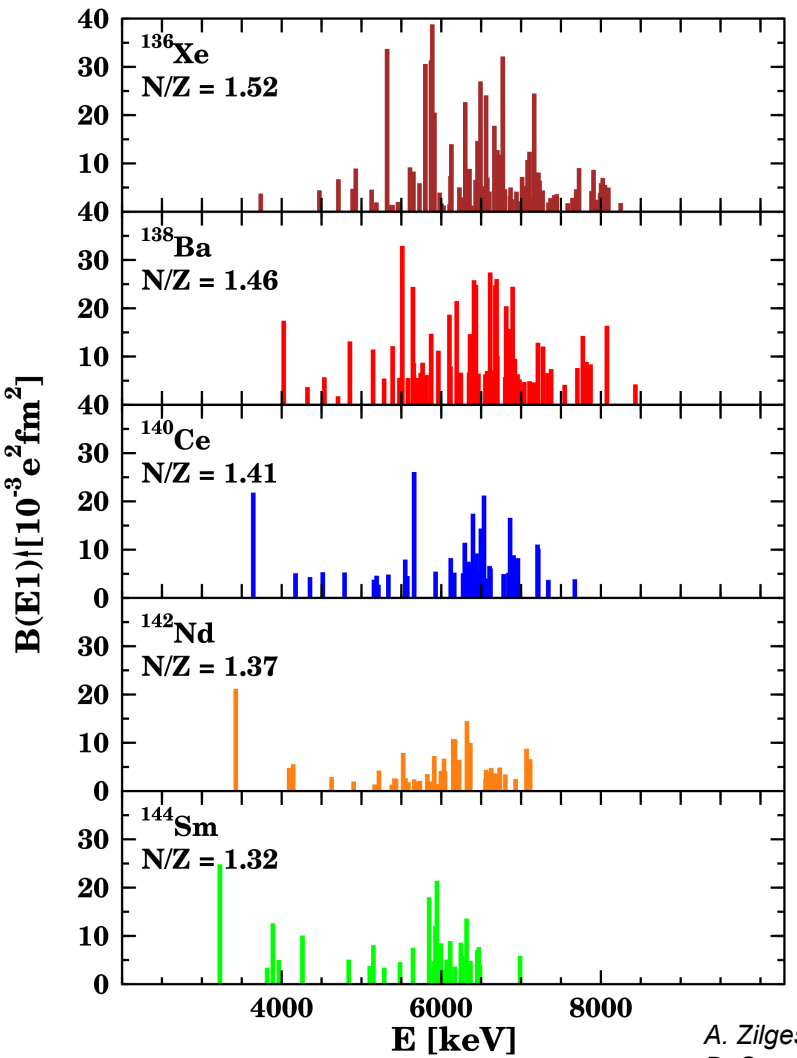
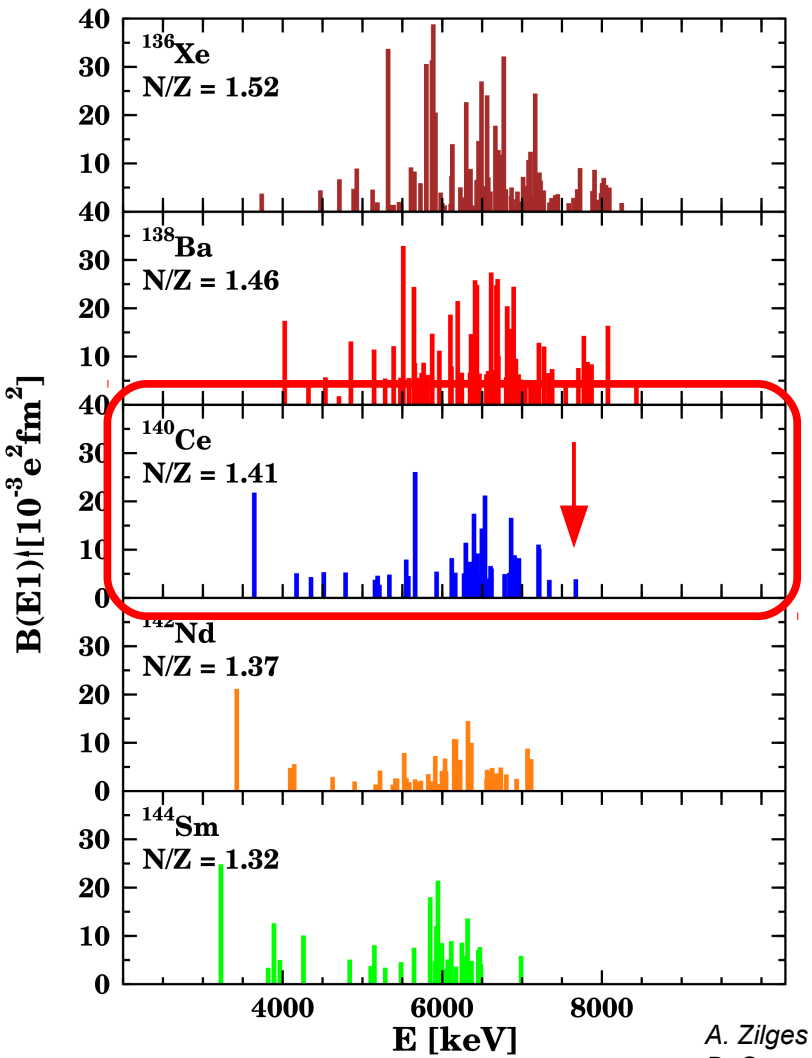


Systematics of the PDR:

- **Concentrated around 5-7 MeV**
- **Strong fragmentation**
- **Summed strength may scale with N/Z**

*A. Zilges et al., PLB **542**, 43 (2002).*
*D. Savran et al., Prog. Part. Nucl. Phys. **70**, (2013) 210-245*

Experiments



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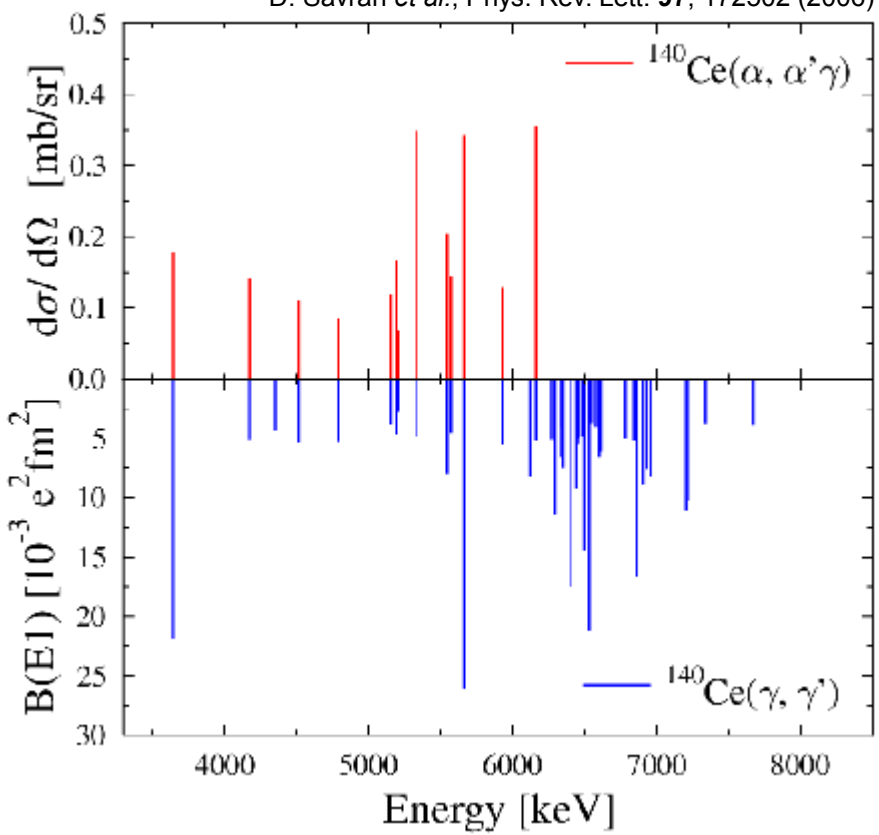
^{140}Ce (γ,γ')

D. Savran *et al.*, Phys. Rev. Lett. **97**, 172502 (2006)



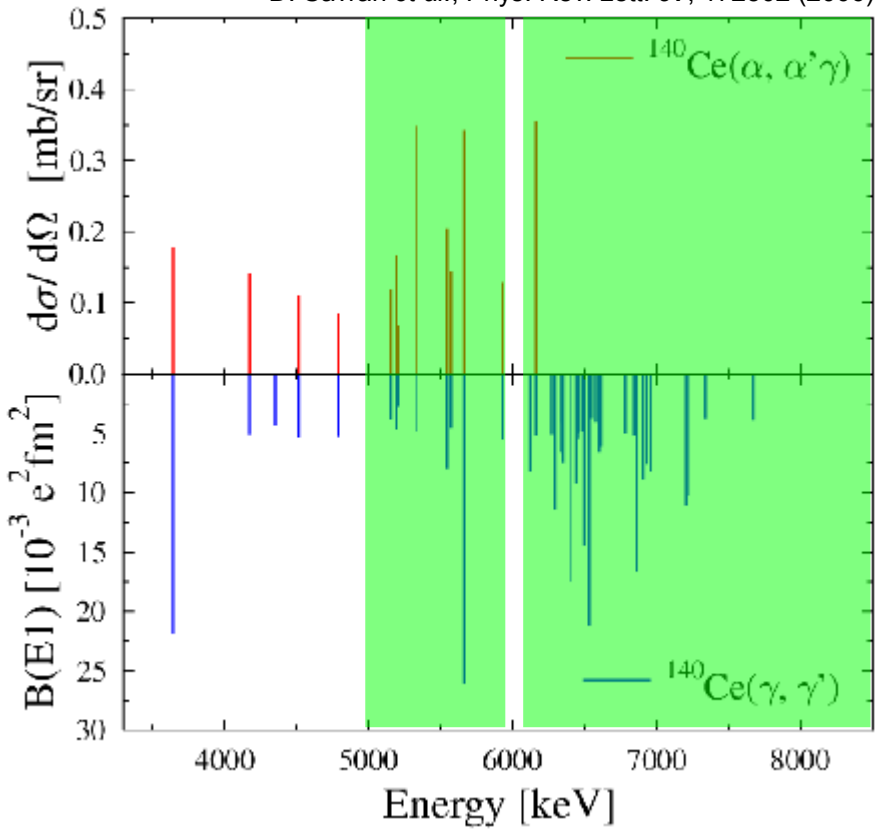
Experiment at HIγS:

- 5 days of beamtime
- 11 Beam energies (+2 in 2013)
- ~100 h beam on target
- Target: 2.35 g enriched $^{140}CeO_2$

Splitting of PDR observed with different probes
→ Decay pattern may yield additional information

^{140}Ce (γ,γ')

D. Savran *et al.*, Phys. Rev. Lett. **97**, 172502 (2006)



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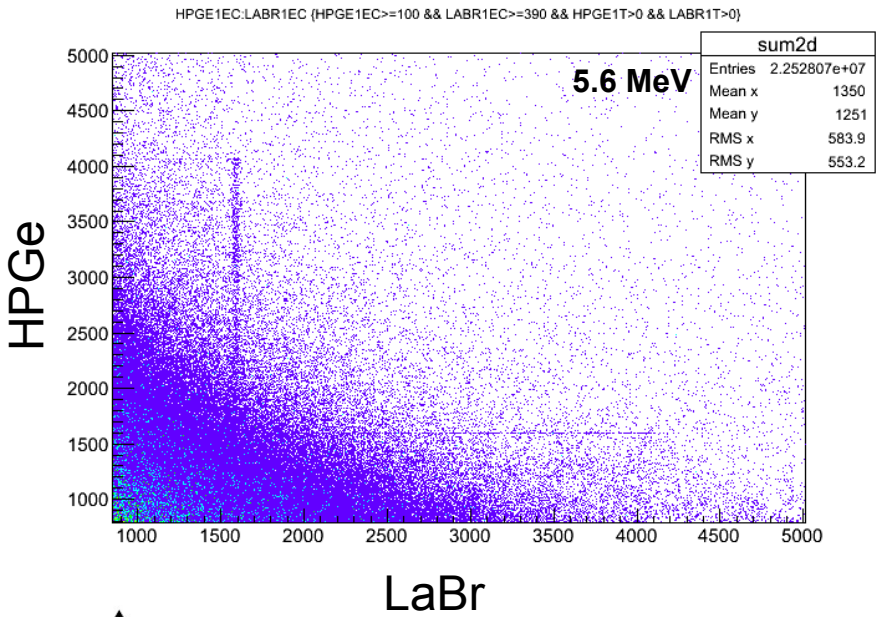
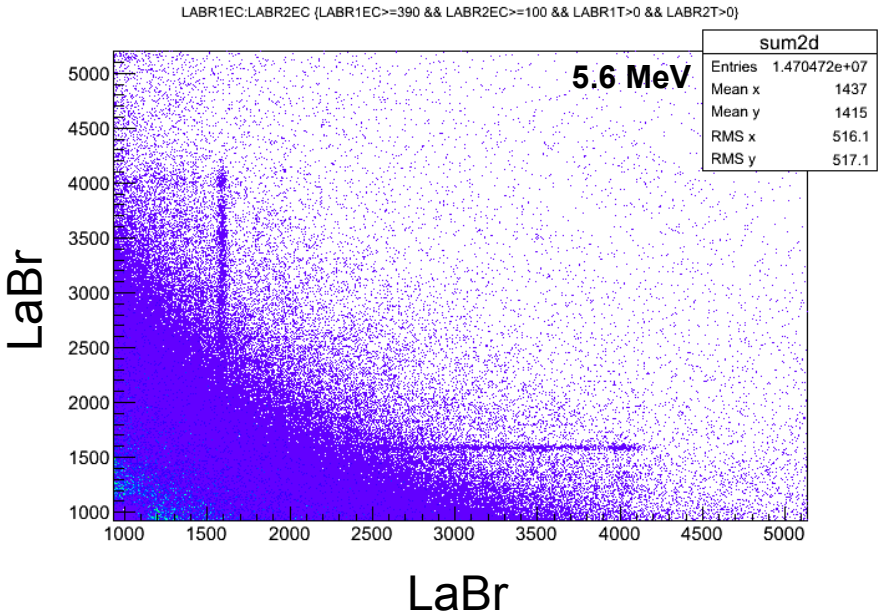
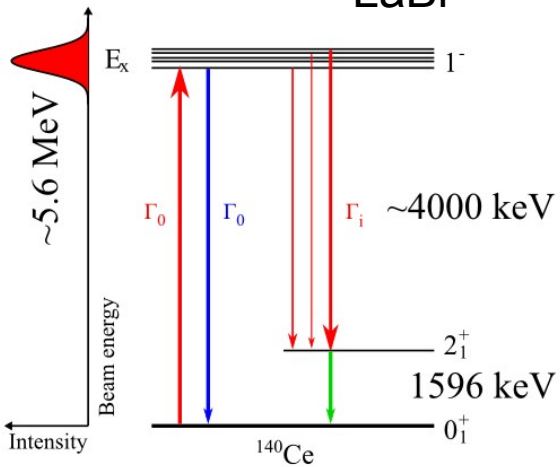
^{140}Ce (γ,γ')

Experimental data yields two matrices:

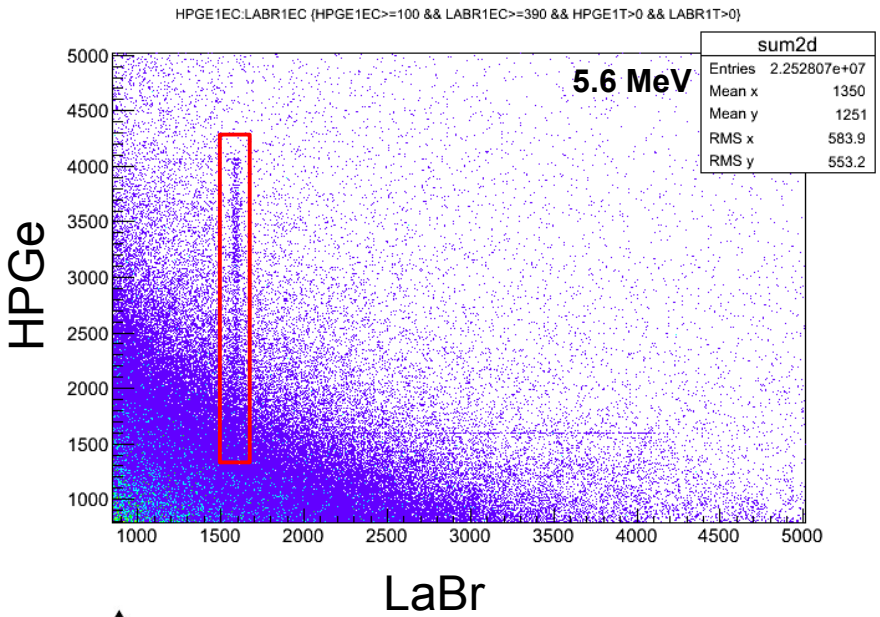


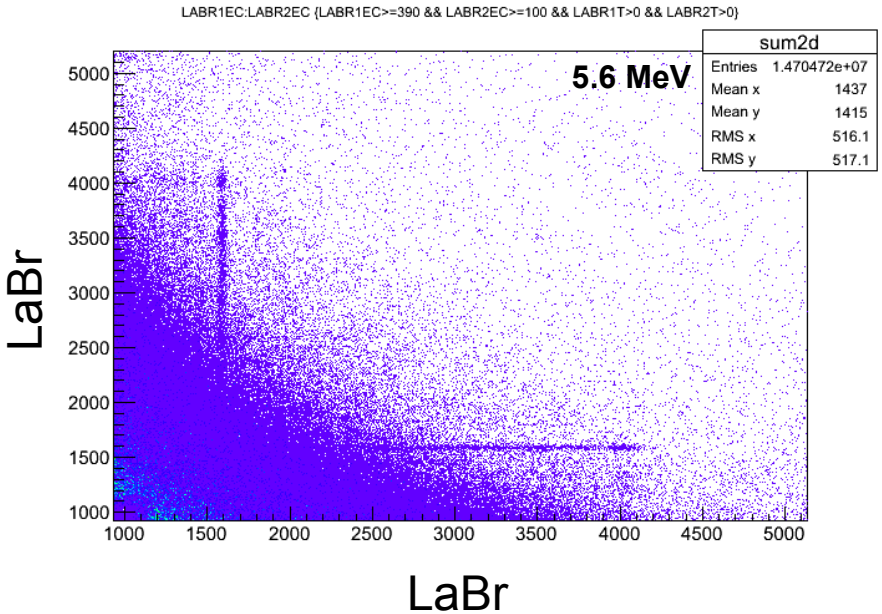


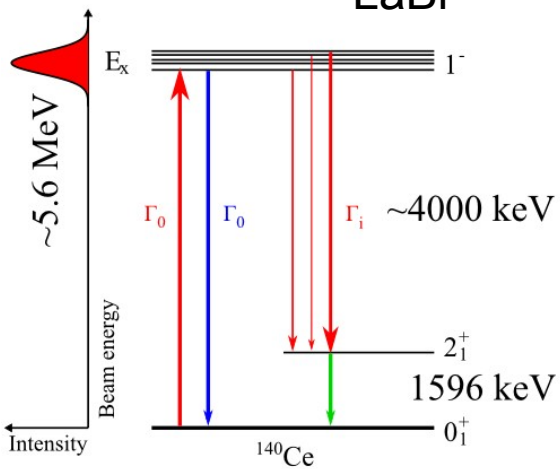


^{140}Ce (γ,γ')

Experimental data yields two matrices:





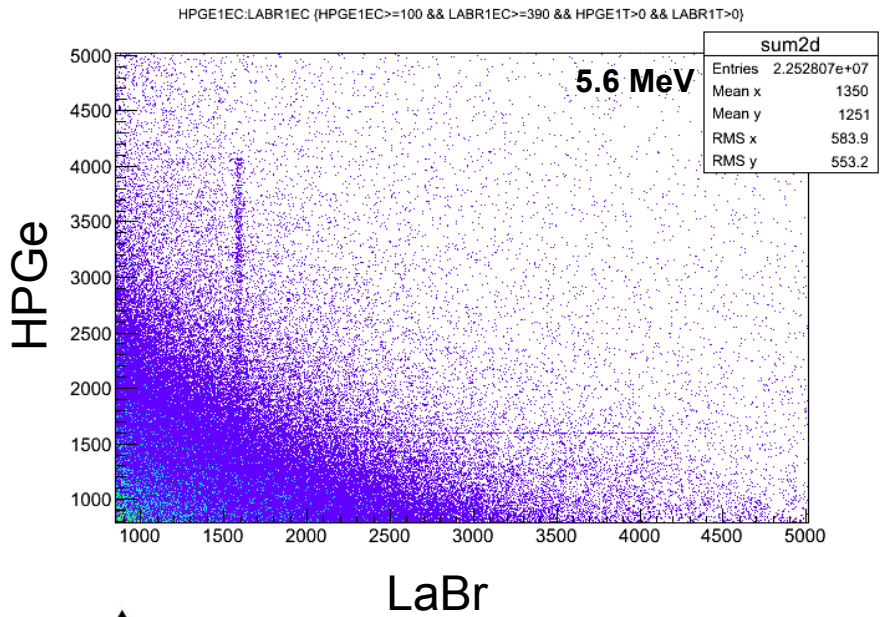


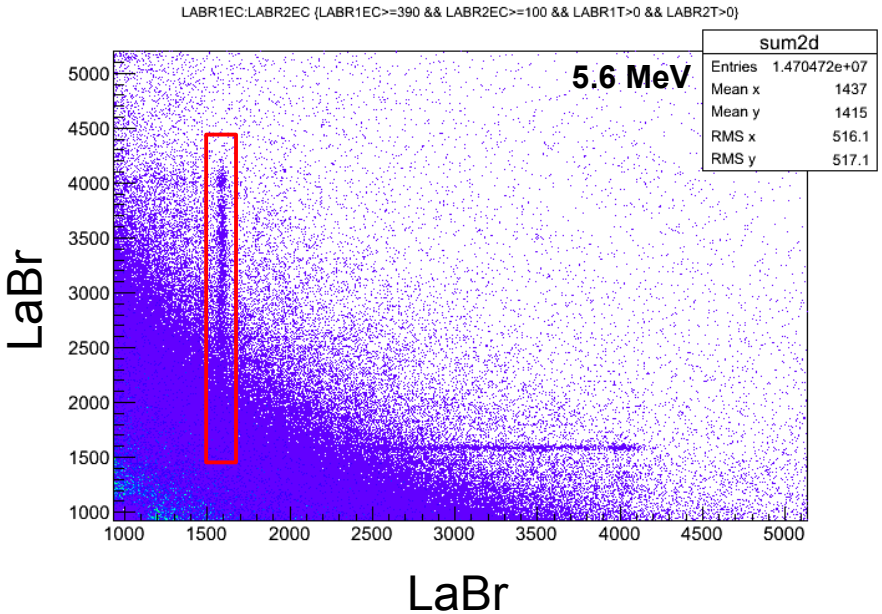
Possible analyses:

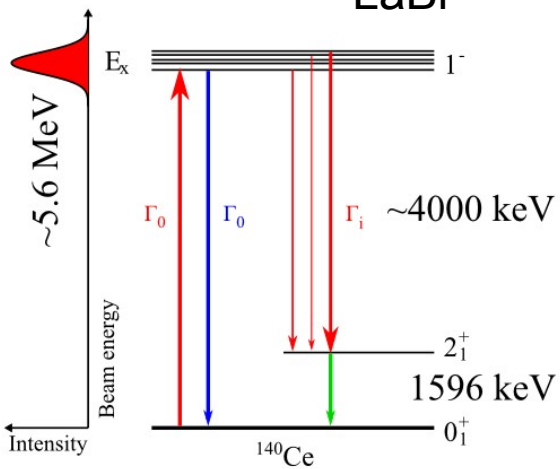
- Gate on $2^+_1 \rightarrow 0^+$ in LaBr:
  1) HPGe spectra (high resolution → single states)

^{140}Ce (γ,γ')

Experimental data yields two matrices:





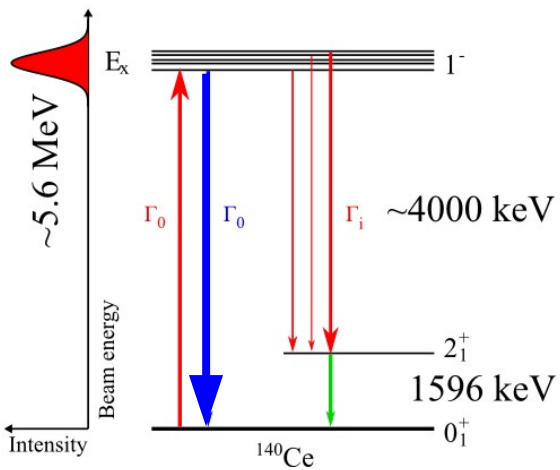


Possible analyses:

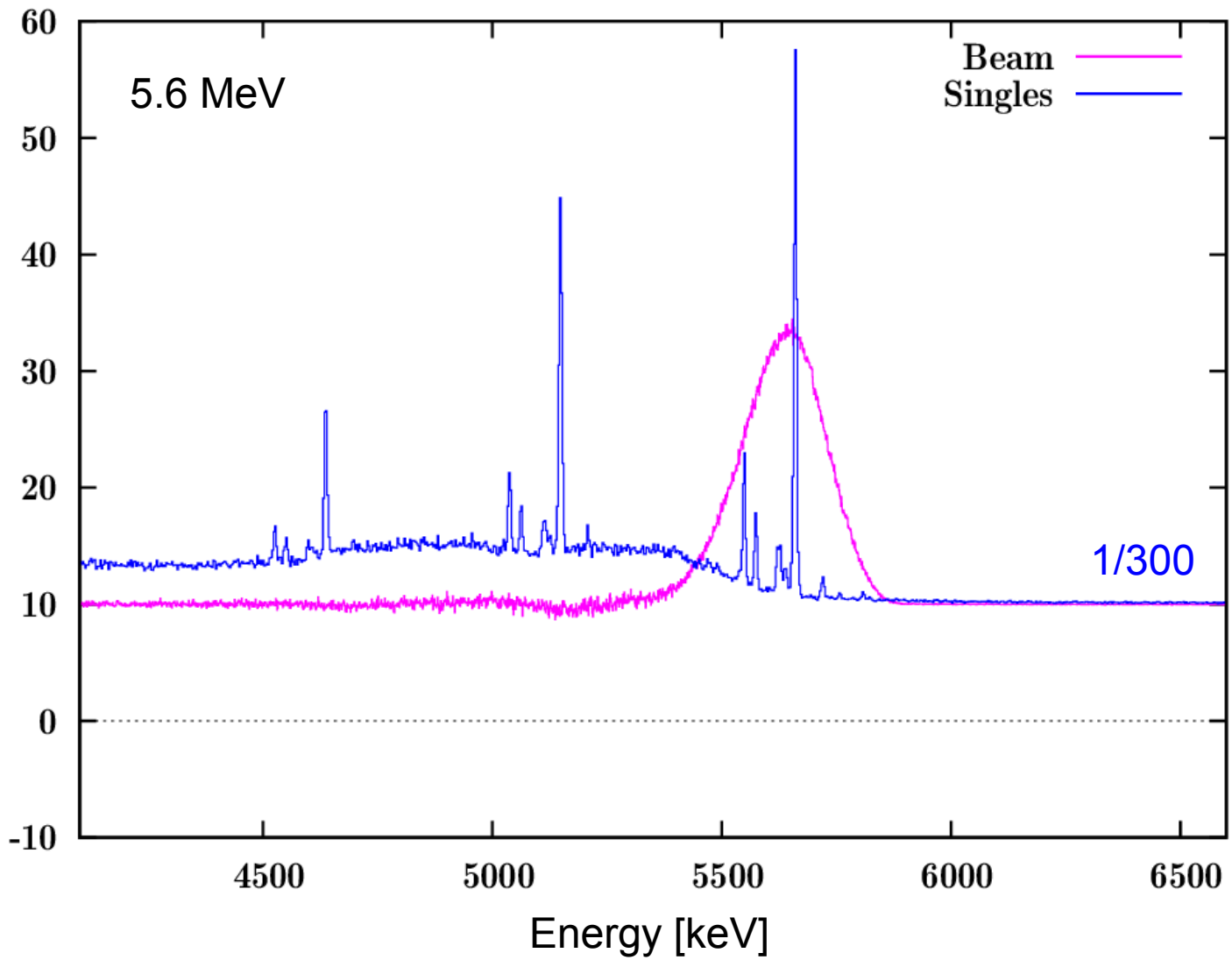
- Gate on $2^+_1 \rightarrow 0^+$ in LaBr:
  1) HPGe spectra (high resolution → single states)
  2) LaBr spectra (better efficiency → averaged)

^{140}Ce (γ,γ')

Gate on LaBr → HPGe spectra

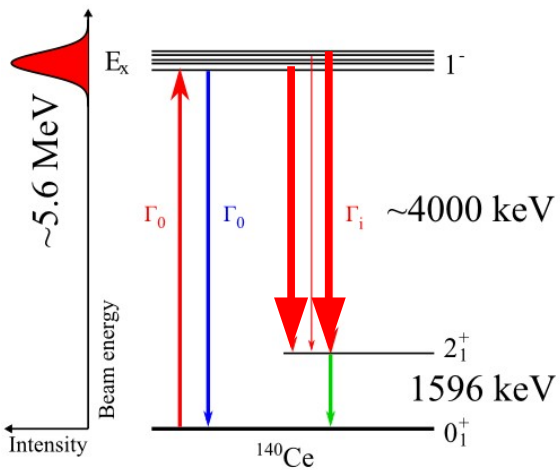


$E(2^+_1)$ = 1596 keV

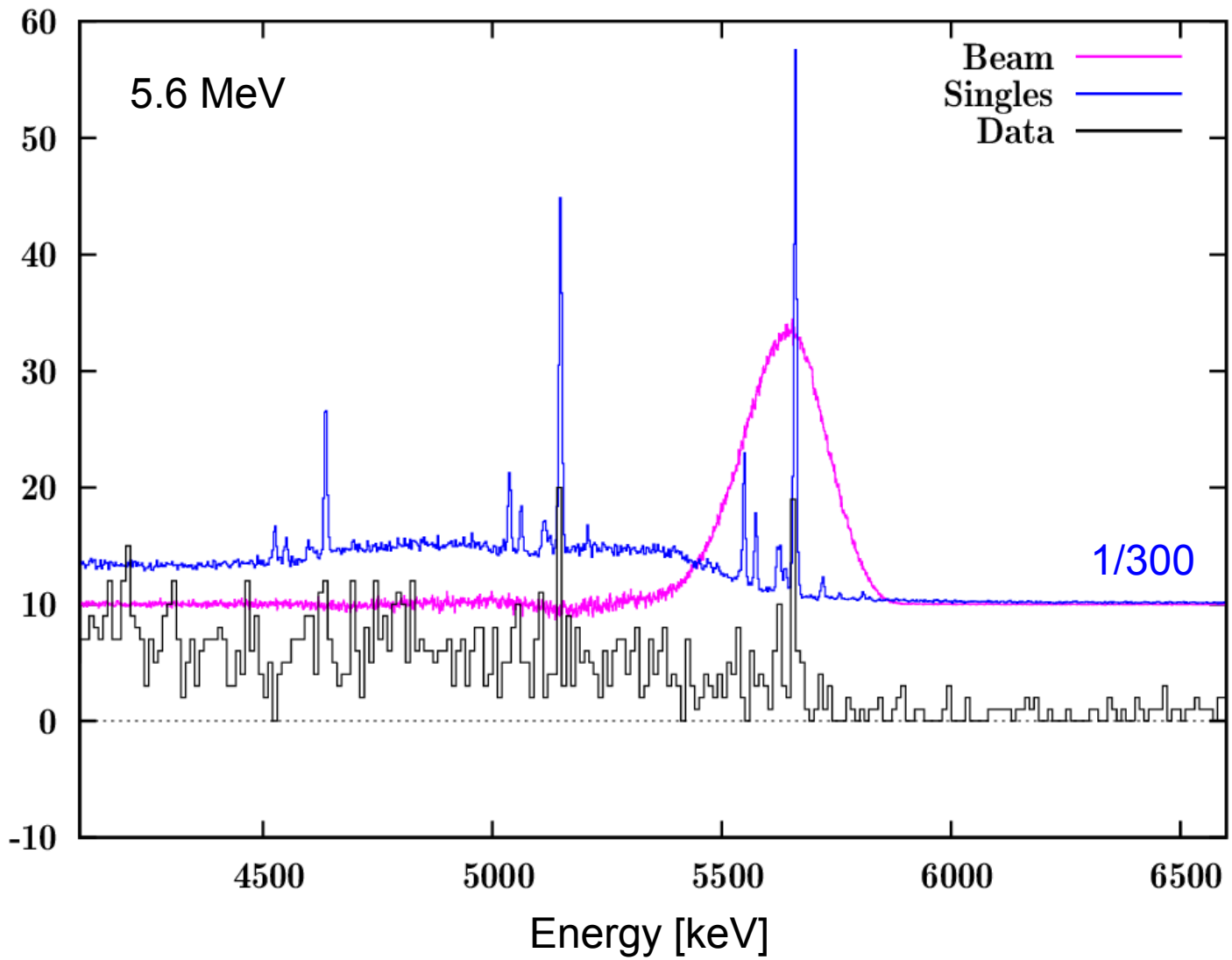


^{140}Ce (γ,γ')

Gate on LaBr → HPGe spectra

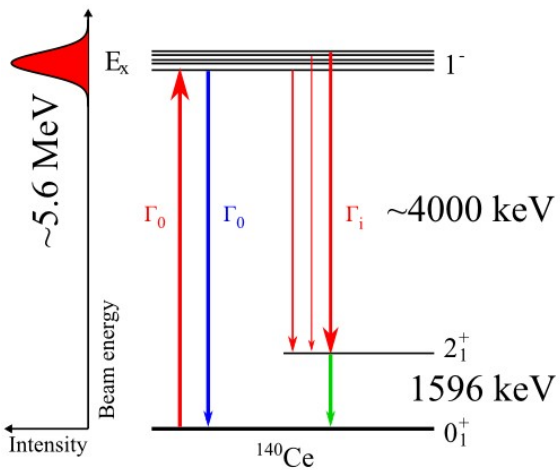


$E(2^+_1)$ = 1596 keV



^{140}Ce (γ,γ')

Gate on LaBr → HPGe spectra



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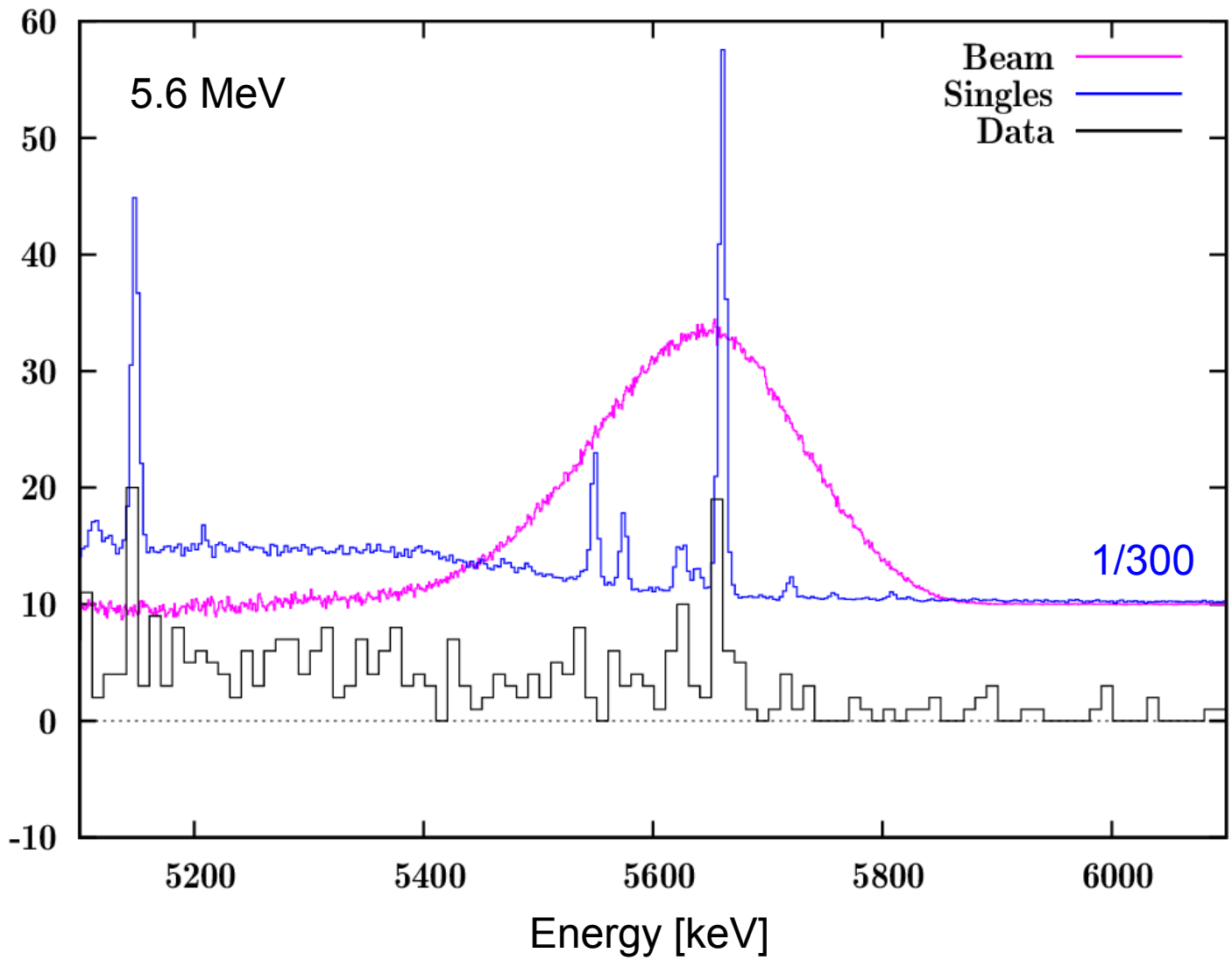
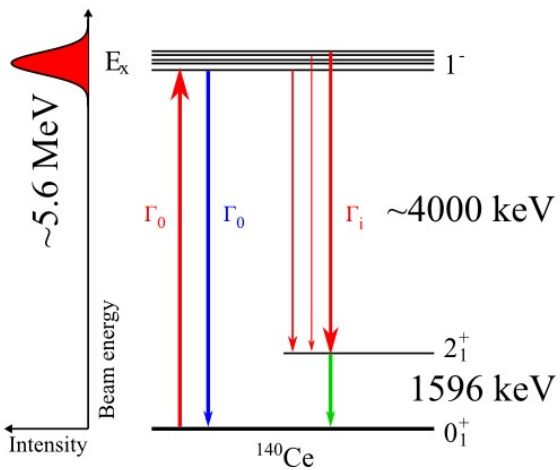
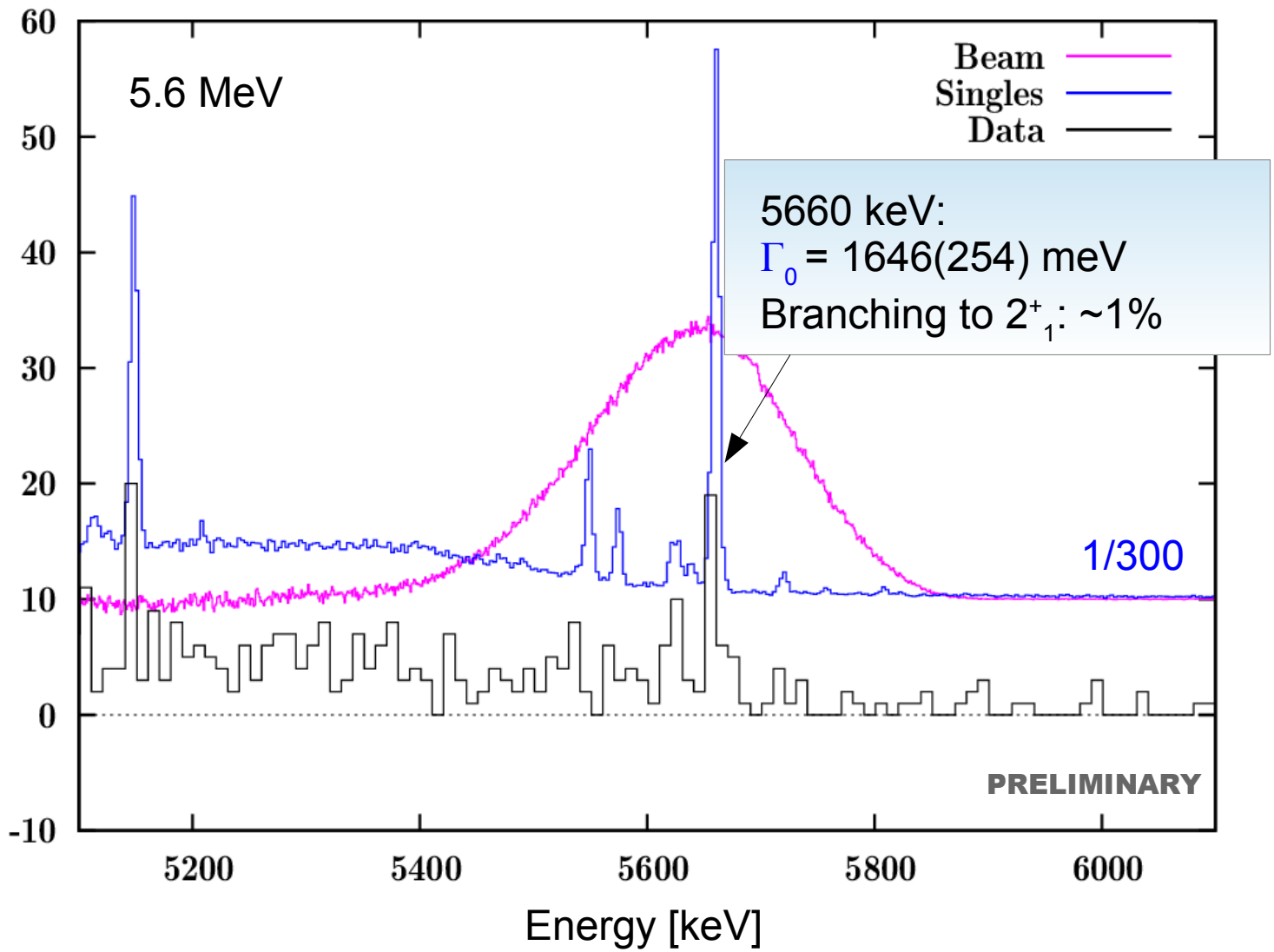


^{140}Ce (γ,γ')

Gate on LaBr → HPGe spectra

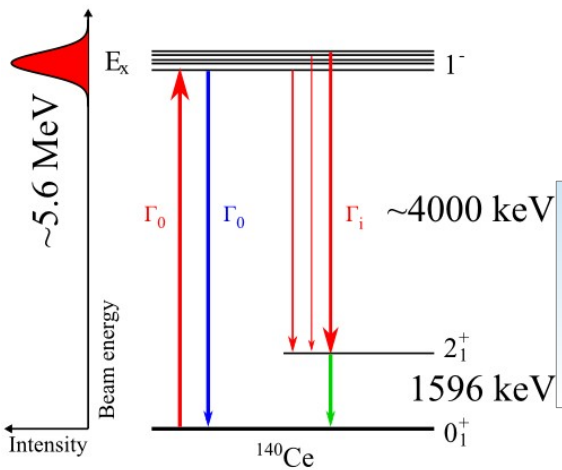


$E(2^+_1)$ = 1596 keV

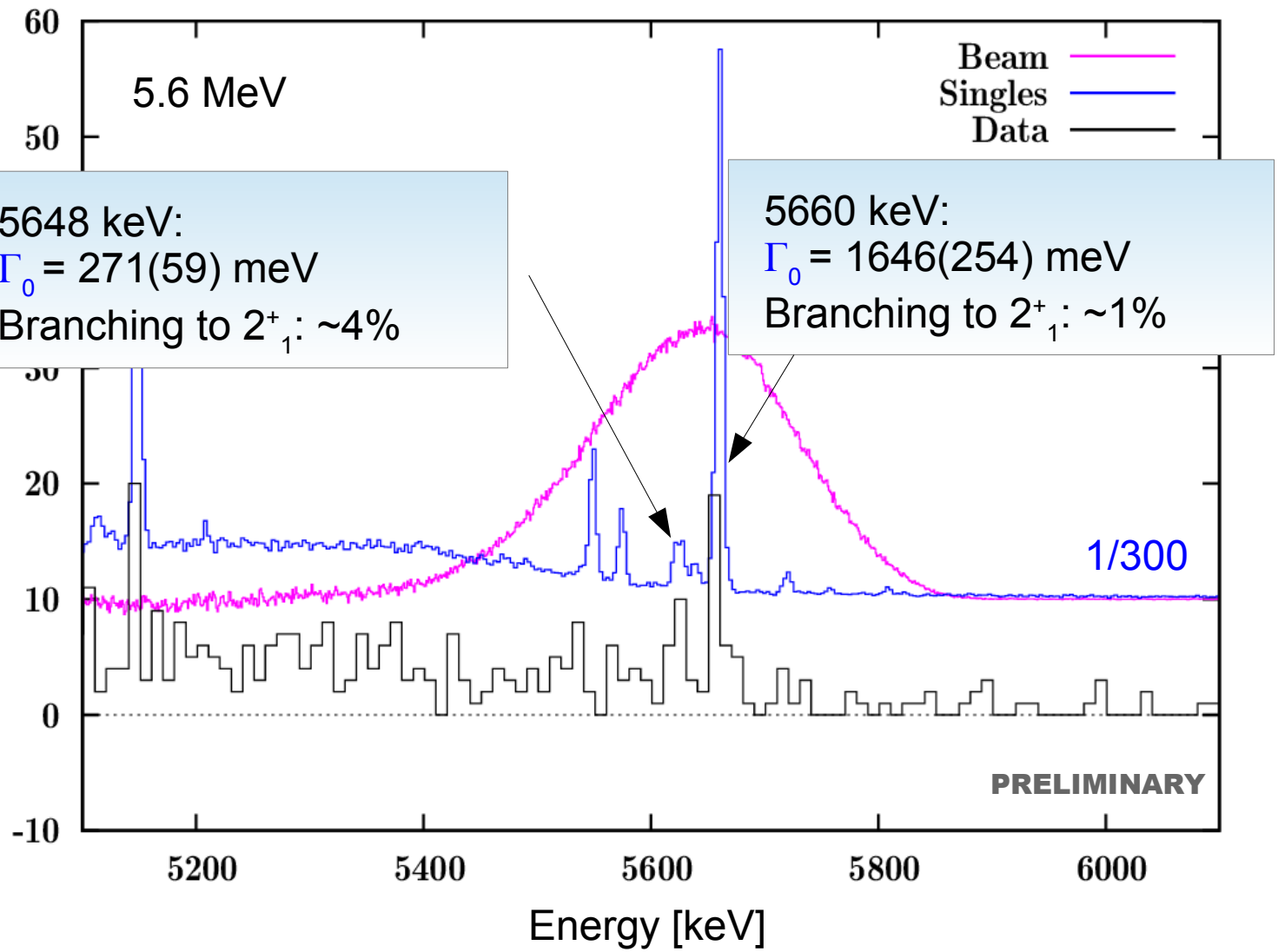


^{140}Ce (γ,γ')

Gate on LaBr → HPGe spectra



$E(2^+_1)$ = 1596 keV

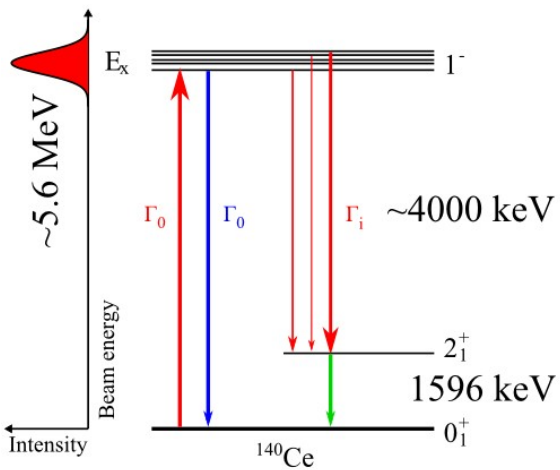


5648 keV:
Γ_0 = 271(59) meV
Branching to 2^+_1: ~4%

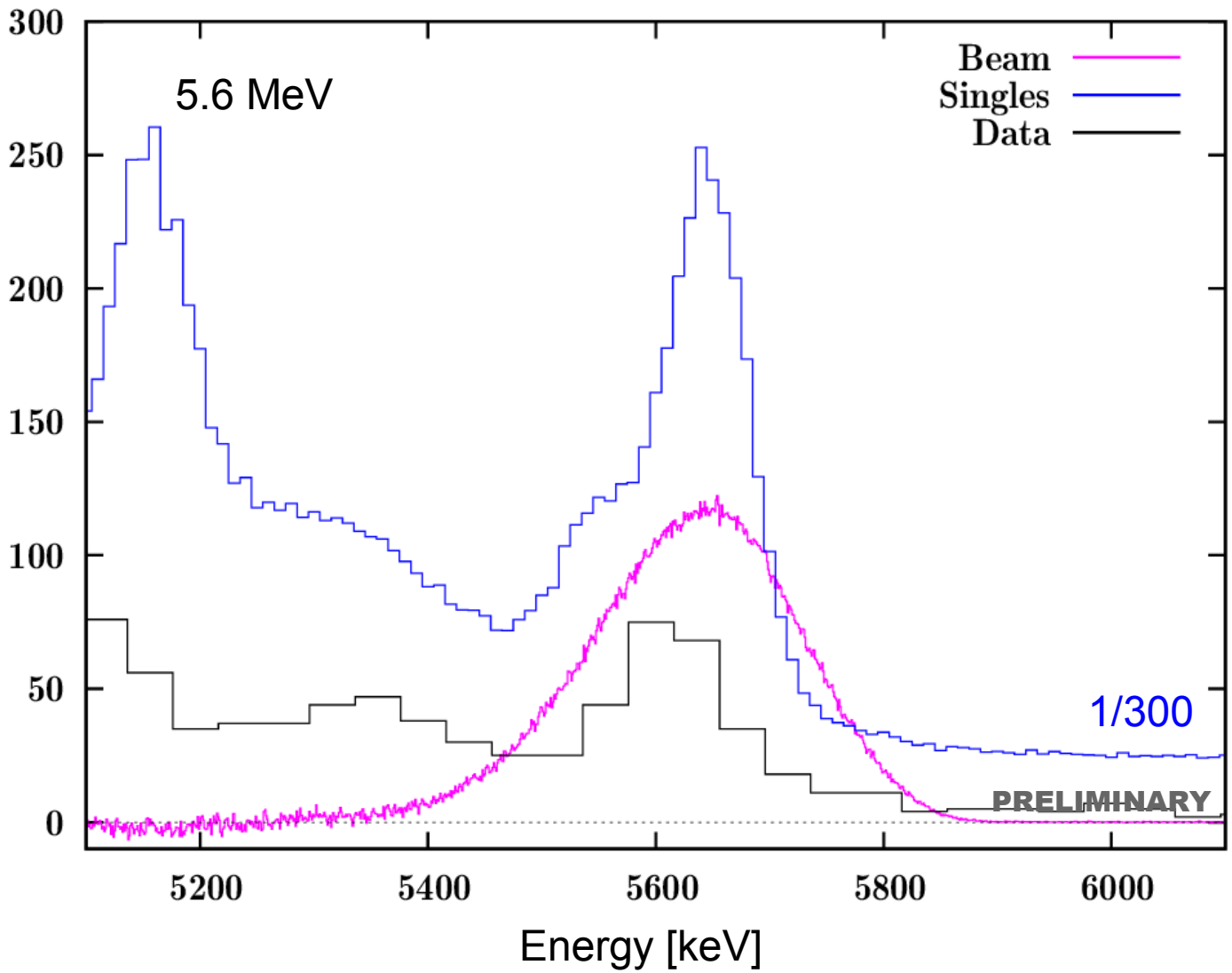
5660 keV:
Γ_0 = 1646(254) meV
Branching to 2^+_1: ~1%

^{140}Ce (γ,γ')

Gate on LaBr → LaBr spectra

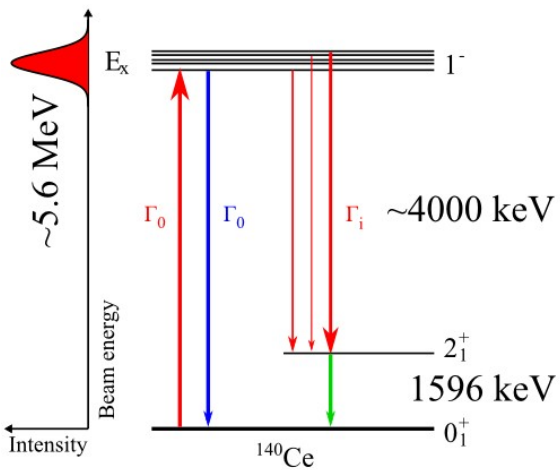


$E(2^+_1)$ = 1596 keV



^{140}Ce (γ,γ')

Gate on LaBr → LaBr spectra



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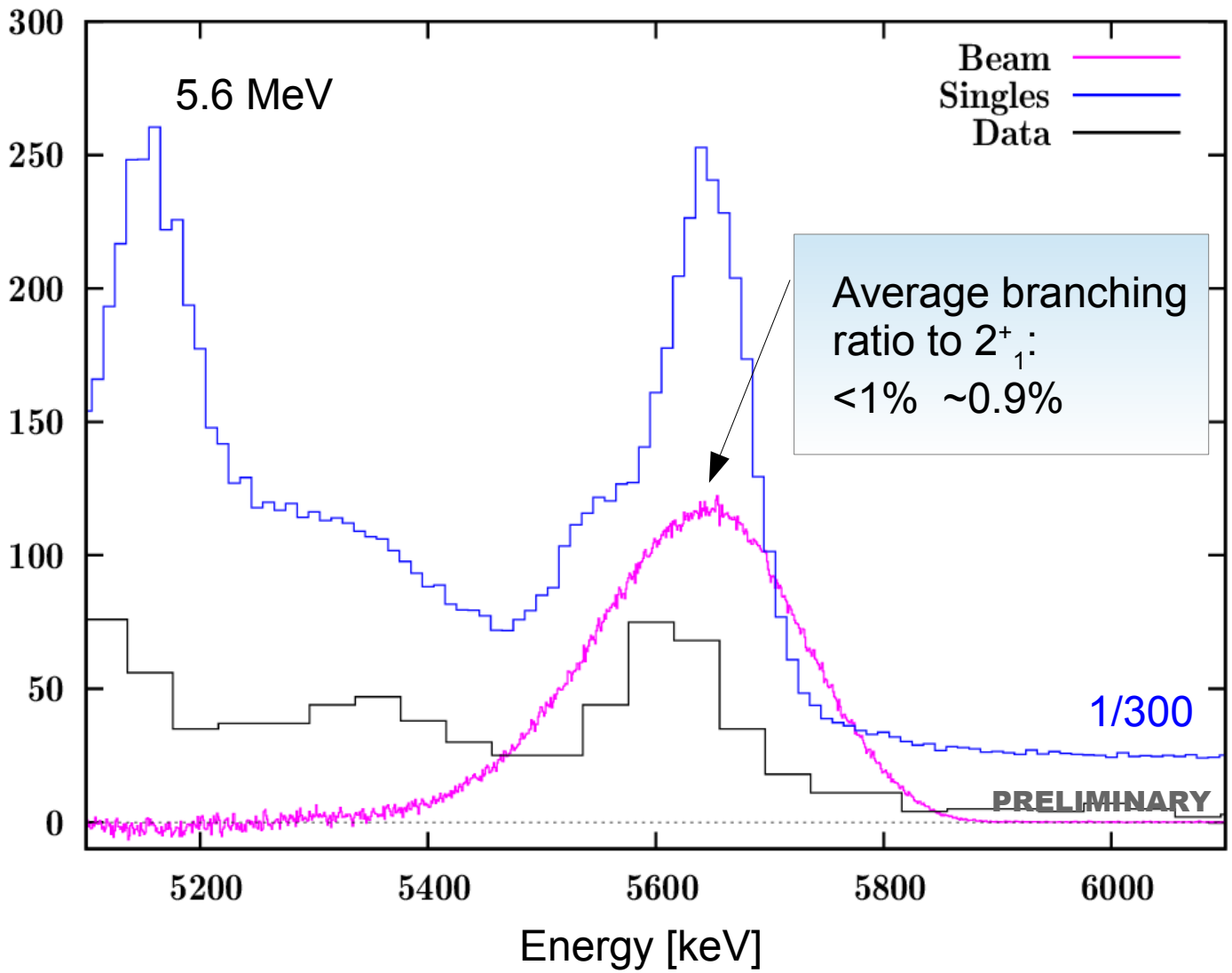
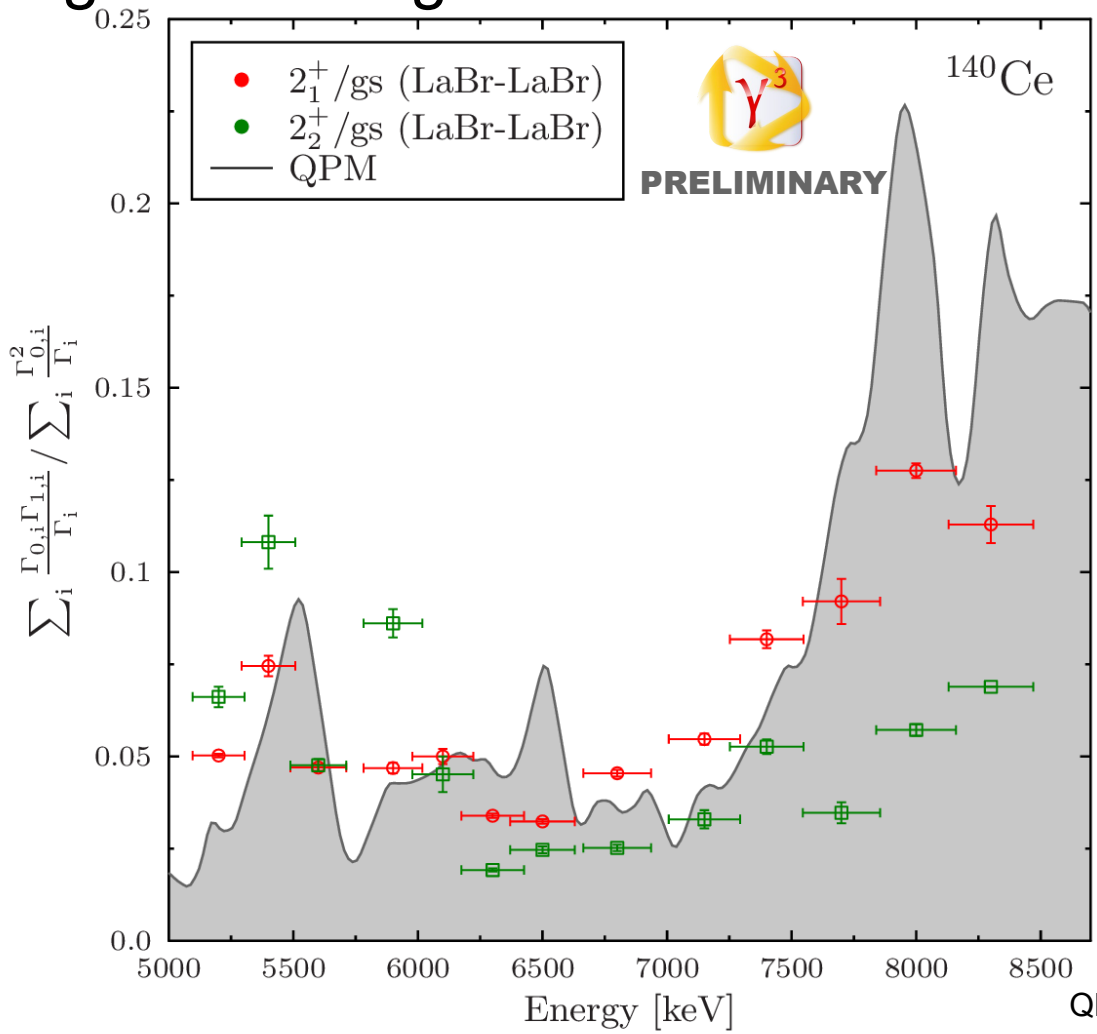


^{140}Ce (γ,γ')

Average branching ratio to first excited states



Only statistical errors

QPM: V.Yu. Ponomarev, priv. comm.

^{140}Ce (γ,γ')

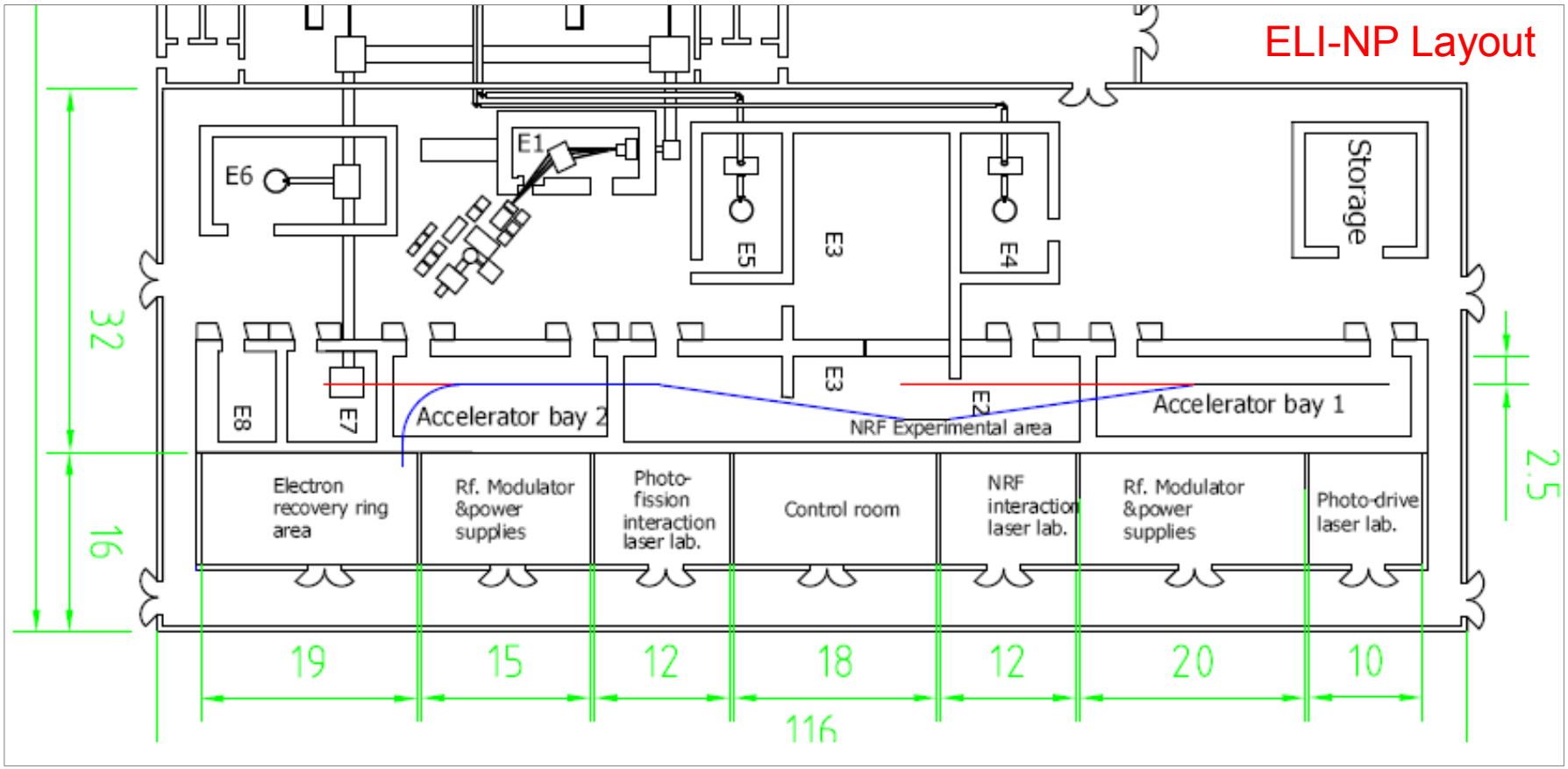
- Determine branching ratios of single states (Sensitivity 1-5%)
- Average branching ratios (Sensitivity ~1%)
- Upper limits for unobserved branchings

Towards ELI-NP

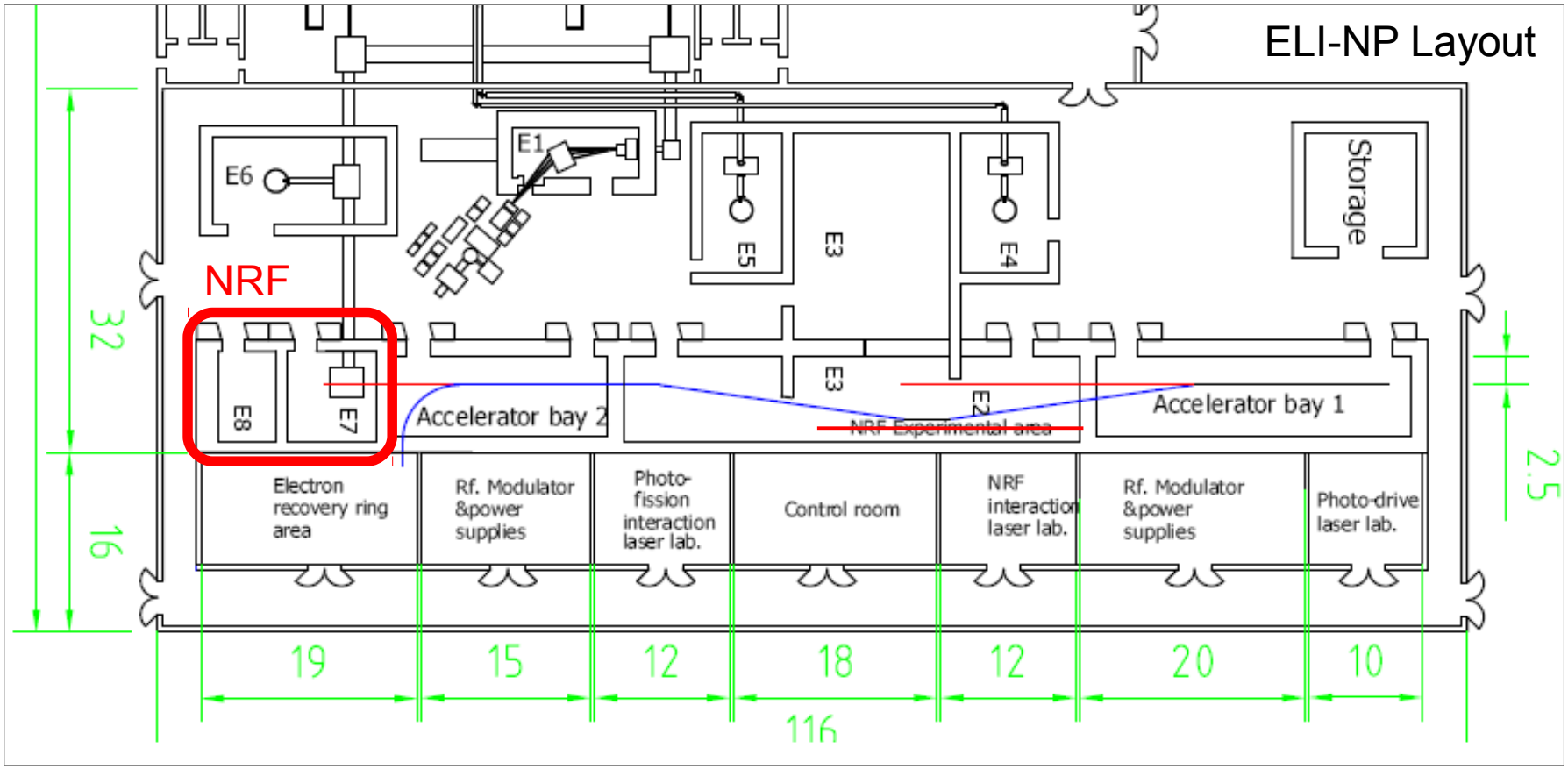
Towards ELI-NP

- ELI-NP (Extreme Light Infrastructure – Nuclear Physics)
- New high intensity light source in Europe
- Uses LCBS to produce high Energy γ beams

Towards ELI-NP



Towards ELI-NP



Towards ELI-NP

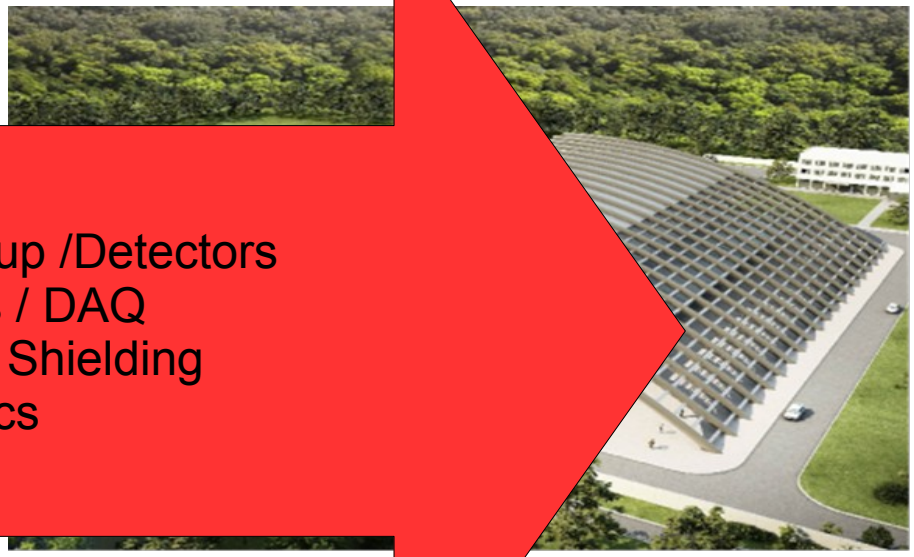
What do we learn from γ^3 for the upcoming ELI?

Flux on target: 10^5 / (s keV)
Resolution: ~ 3%
Energy: 1 – 100 MeV

Flux on target: 10^7 / (s keV)
Resolution: < 0.5%
Energy: < 20 MeV

Towards ELI-NP

What do we learn from γ^3 for the upcoming ELI?



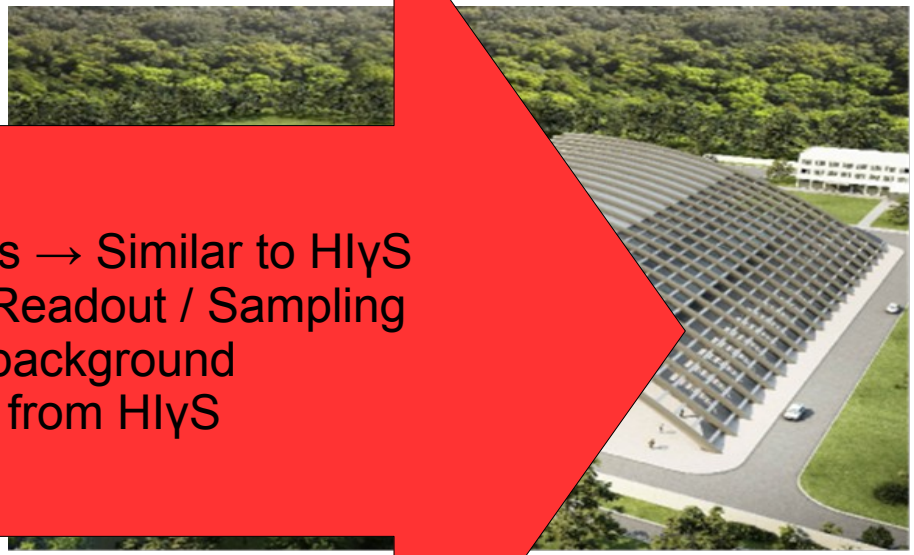
Experimental setup /Detectors
Electronics / DAQ
Background / Shielding
Physics

Flux on target: 10^5 / keV)
Resolution: ~ 3%
Energy: 1 – 100 MeV

Flux on target: 10 (s keV)
Resolution: < 0.5
Energy: < 20 MeV

Towards ELI-NP

What do we learn from γ^3 for the upcoming ELI?



Experimental setup /Detectors → Similar to HIγS
Electronics / DAQ → Digital Readout / Sampling
Background → less background
Physics → Anything from HIγS

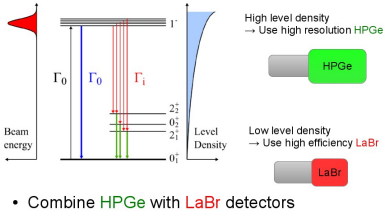
Flux on target: 10^5 / keV)
Resolution: ~ 3%
Energy: 1 – 100 MeV

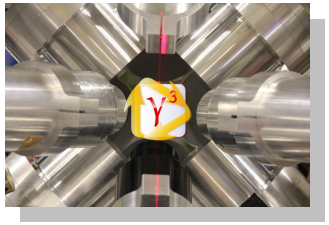
Flux on target: 10 (s keV)
Resolution: < 0.5
Energy: < 20 MeV

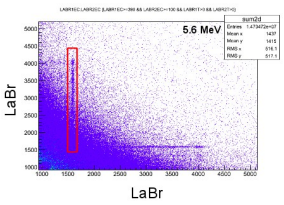
extreme light infrastructure

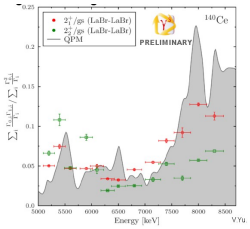
Summary

- γ-γ coincidence method to increase sensitivity for weak transitions
- The new γ^3 setup at HIγS
- Commissioning with ^{32}S
- PDR in ^{140}Ce
- Analysis of coincidences
- Discrete and Average branching ratio, Are in agreement with QPM
- Future project: ELI-NP

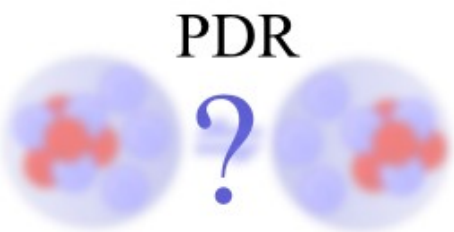


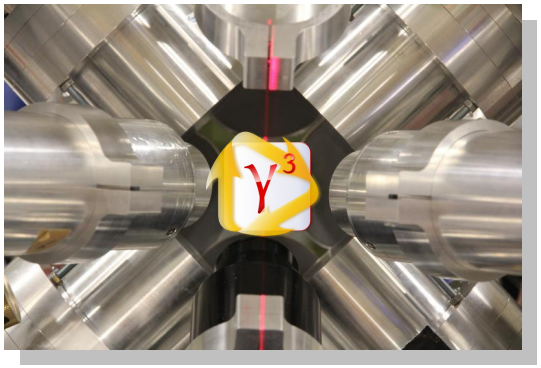


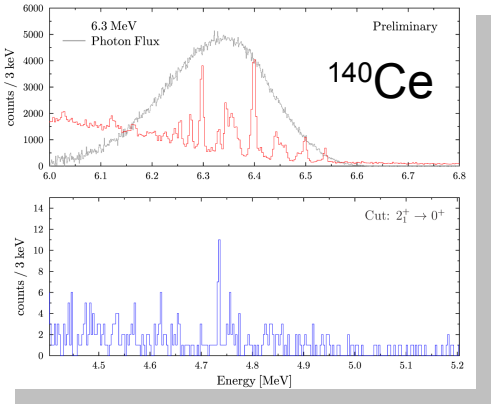




γ³ Collaboration







- **EMMI/GSI**
  - B.Löher, E.Fiori, J.Isaak, D.Savran, J.Silva
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  - V.Derya, J.Endres, A.Zilges
- **HIγS (Duke University)**
  - M.Bhike, M.Gooden, J.Kelley, A.Tonchev, W.Tornow, H.Weller
- **Yale University**
  - N.Cooper, P.Humby, V.Werner