EMMI

Photon induced γ-γ coincidence experiments at the γ³-setup at HIγS

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Frankfurt Institute for Advanced Studies FIAS

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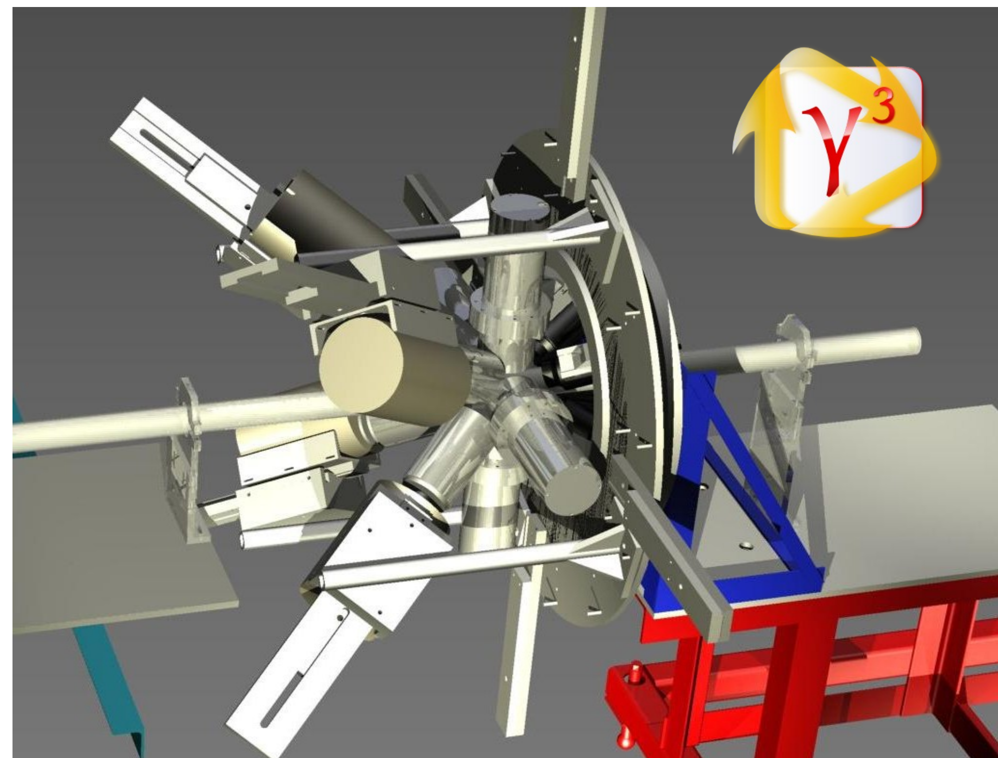

EMMI

GSI

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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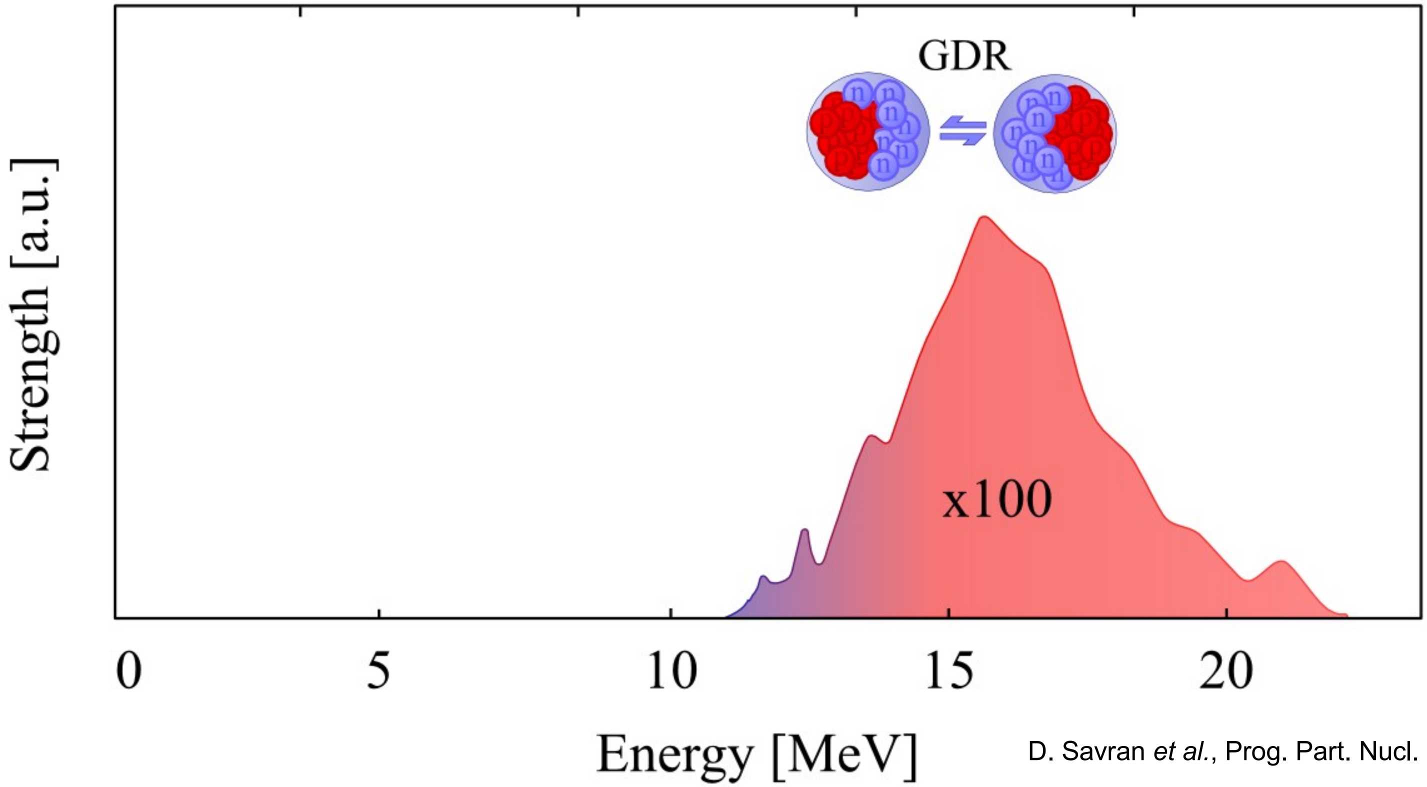

D. Savran *et al.*, Prog. Part. Nucl. Phys. **70**, (2013) 210-245

Photoresponse of (spherical) nuclei

- GDR: Oscillation of Neutrons vs. Protons

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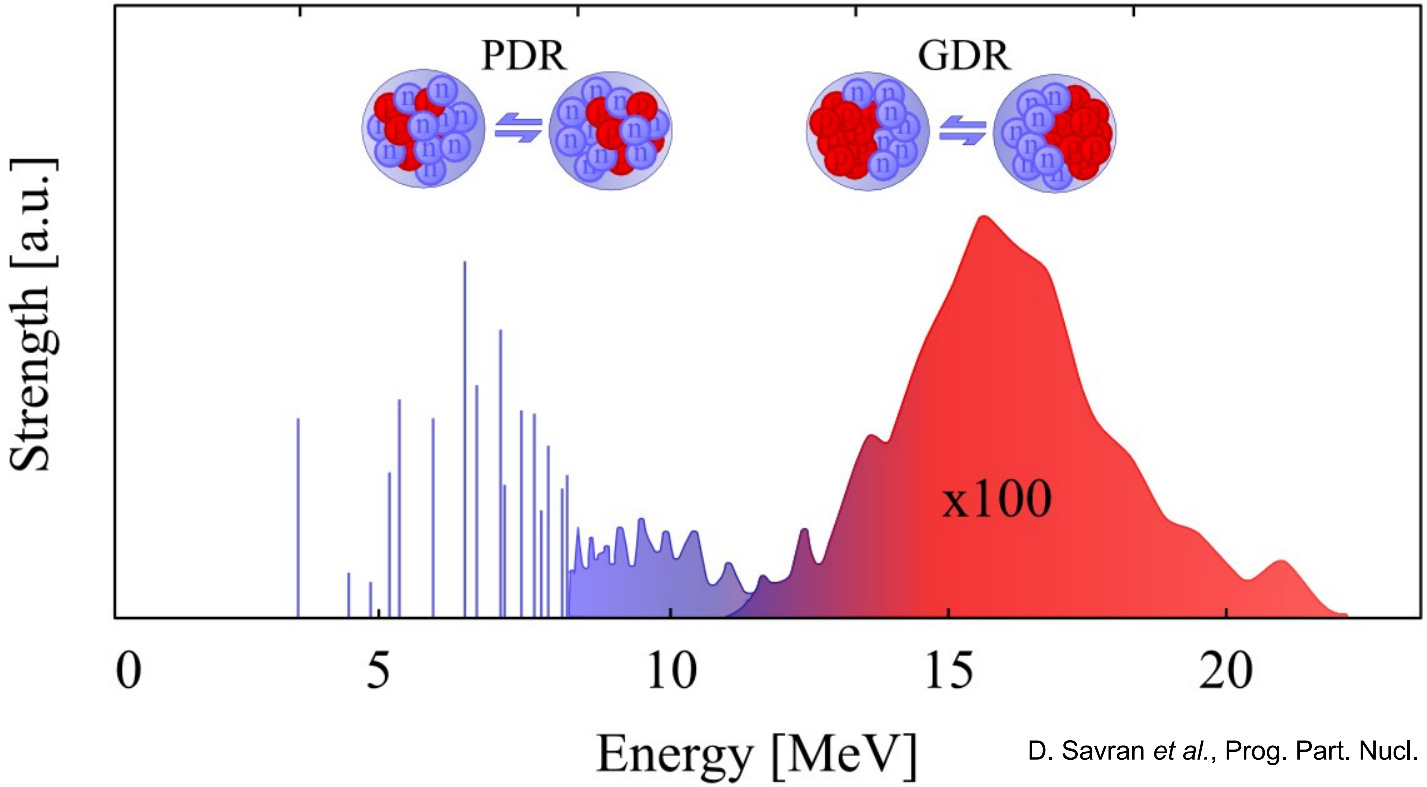

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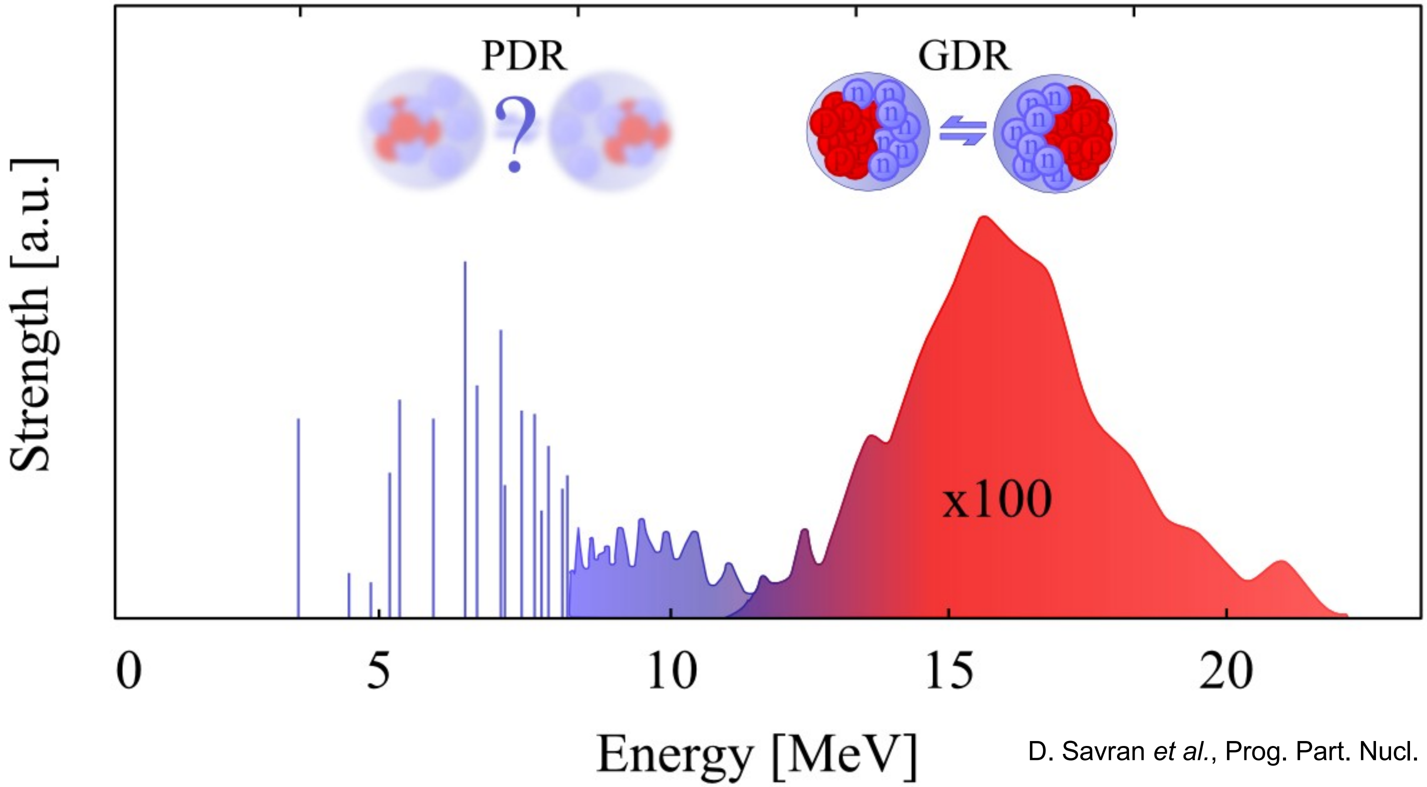
Photoresponse of (spherical) nuclei

- GDR: Oscillation of Neutrons vs. Protons
- PDR: Oscillation of Neutron skin vs. Core

Motivation



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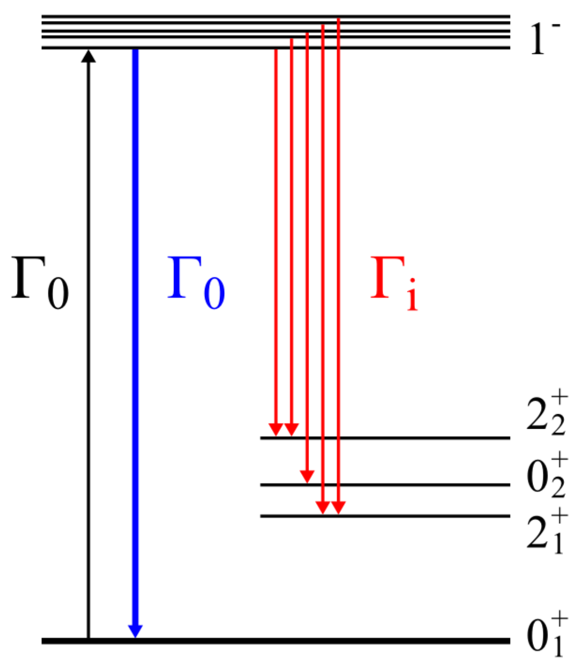
Photoresponse of (spherical) nuclei

- GDR: Oscillation of Neutrons vs. Protons
- PDR: Oscillation of Neutron skin vs. Core
  → Investigate decay behavior ?

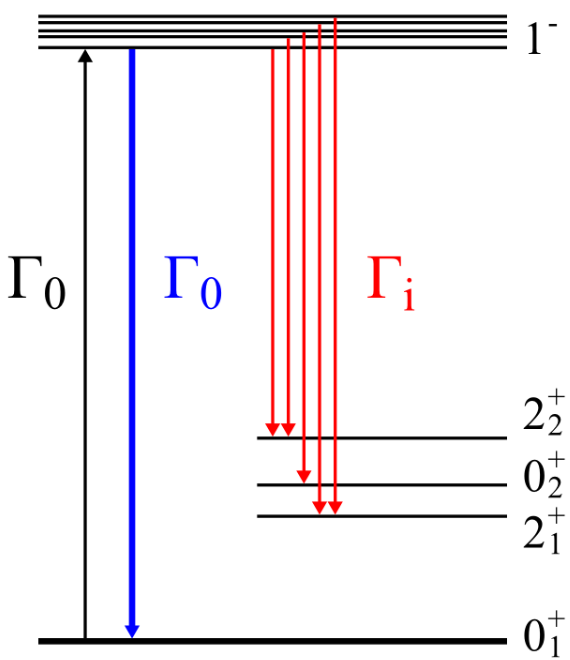
Experimental Method



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

Nuclear Resonance Fluorescence

Experimental Method



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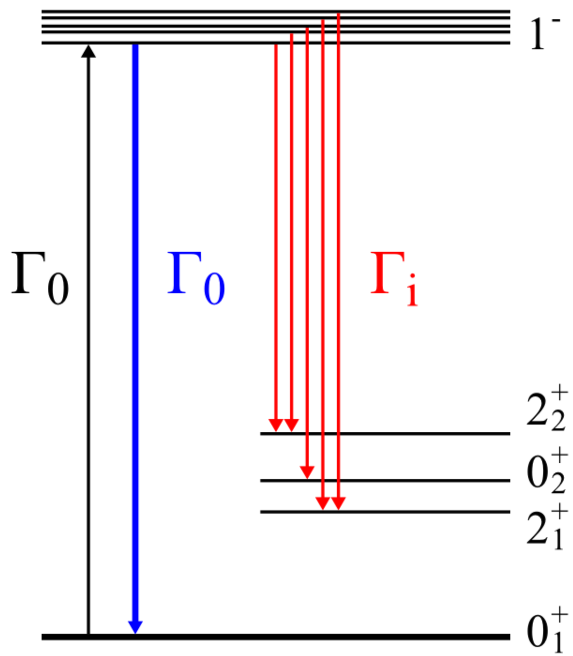
- Elastic channel dominant: ($\Gamma_0 \gg \Gamma_i$)

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

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

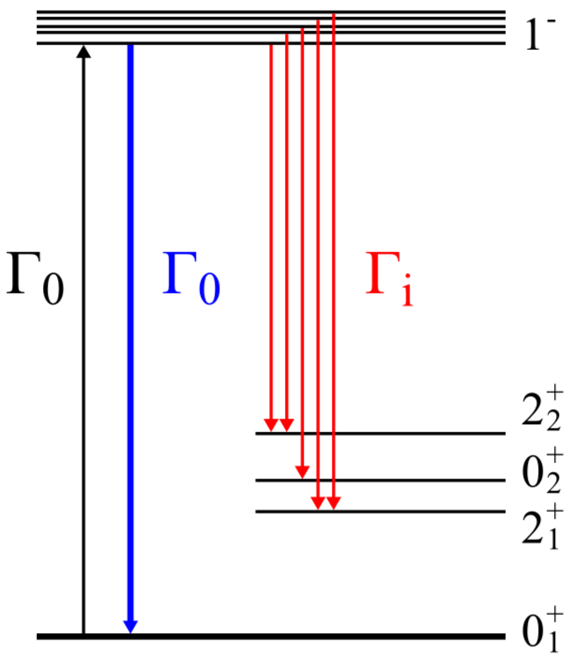
Experimental Method



- Decay „elastic“ (Γ_0) or „inelastic“ (Γ_i)
- Elastic channel dominant: (Γ_0 » Γ_i)

To know the decay pattern, Γ_i need to be determined
→ Challenge: Measure small branching ratios

Experimental Method

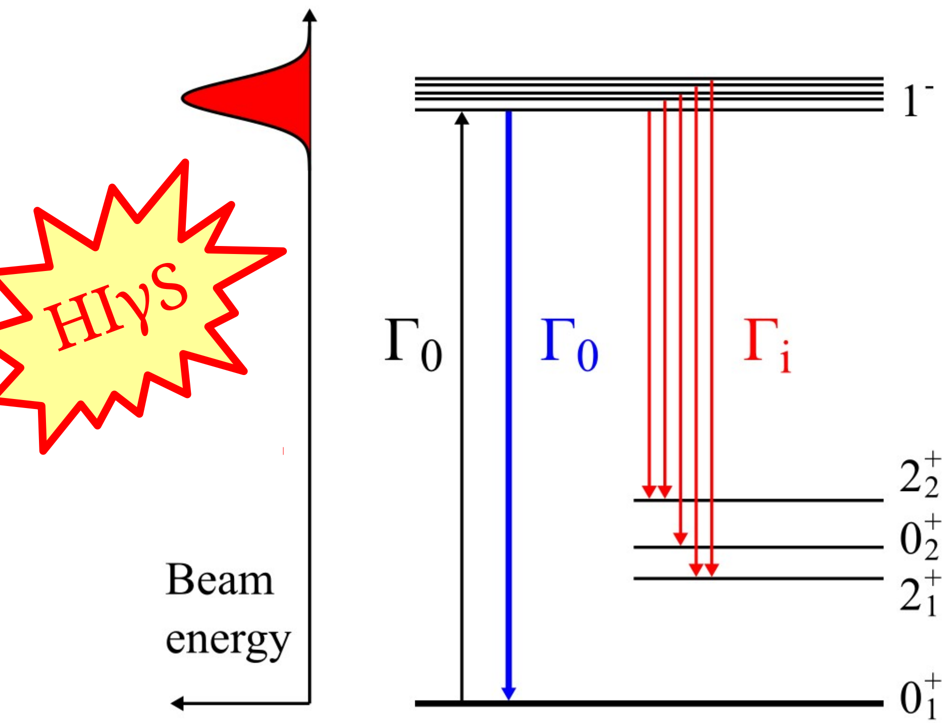


- Decay „elastic“ (Γ_0) or „inelastic“ (Γ_i)
- Elastic channel dominant: (Γ_0 » Γ_i)

Use:

- Selectivity of NRF reaction → Mostly J=1 states

Experimental Method

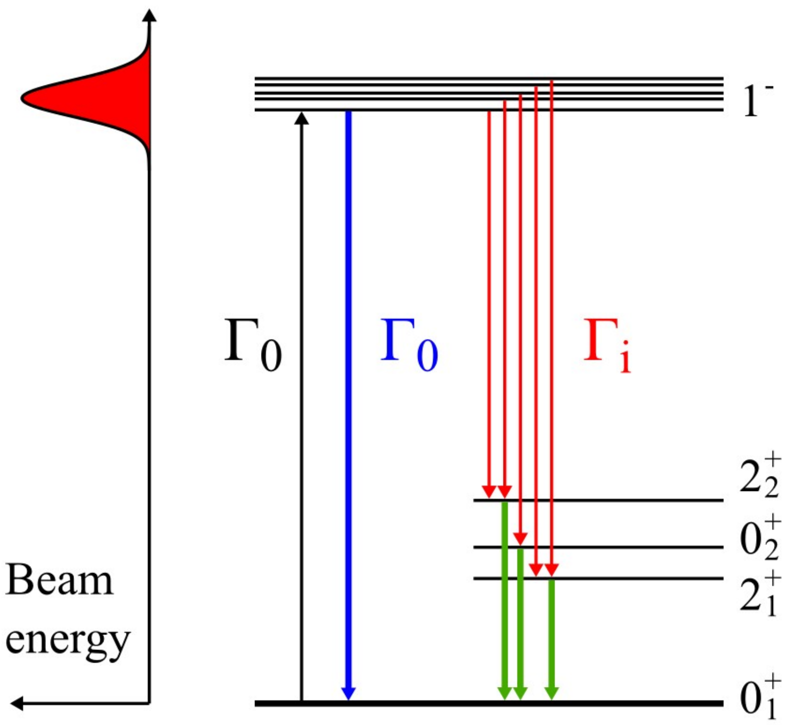


- Decay „elastic“ (Γ_0) or „inelastic“ (Γ_i)
- Elastic channel dominant: ($\Gamma_0 \gg \Gamma_i$)

Use:

- Selectivity of NRF reaction and mono-energetic beam
  → Prepare nucleus in well-defined energy region

Experimental Method

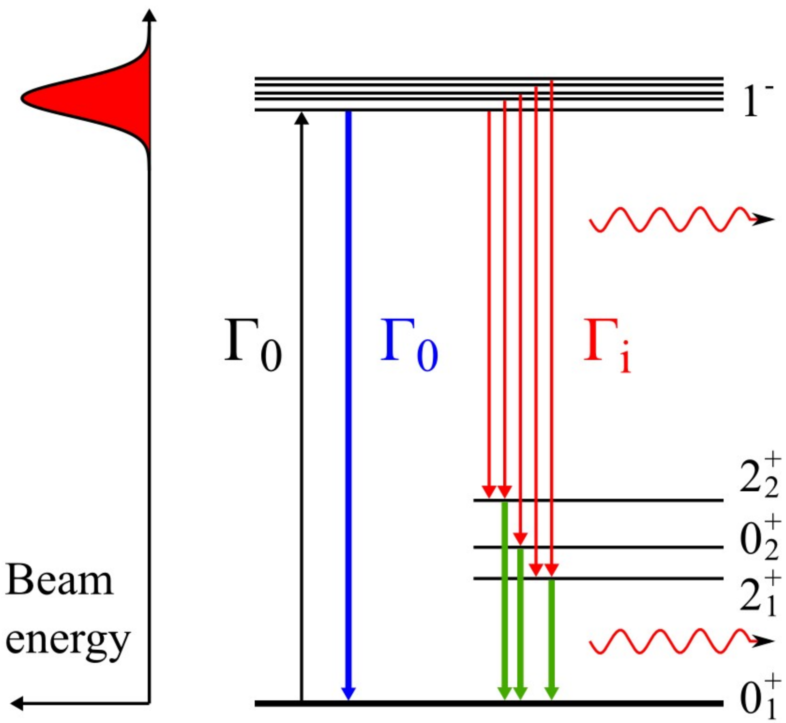


- Decay „elastic“ (Γ_0) or „inelastic“ (Γ_i)
- Elastic channel dominant: ($\Gamma_0 \gg \Gamma_i$)
- Select low energy decay

Combine:

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

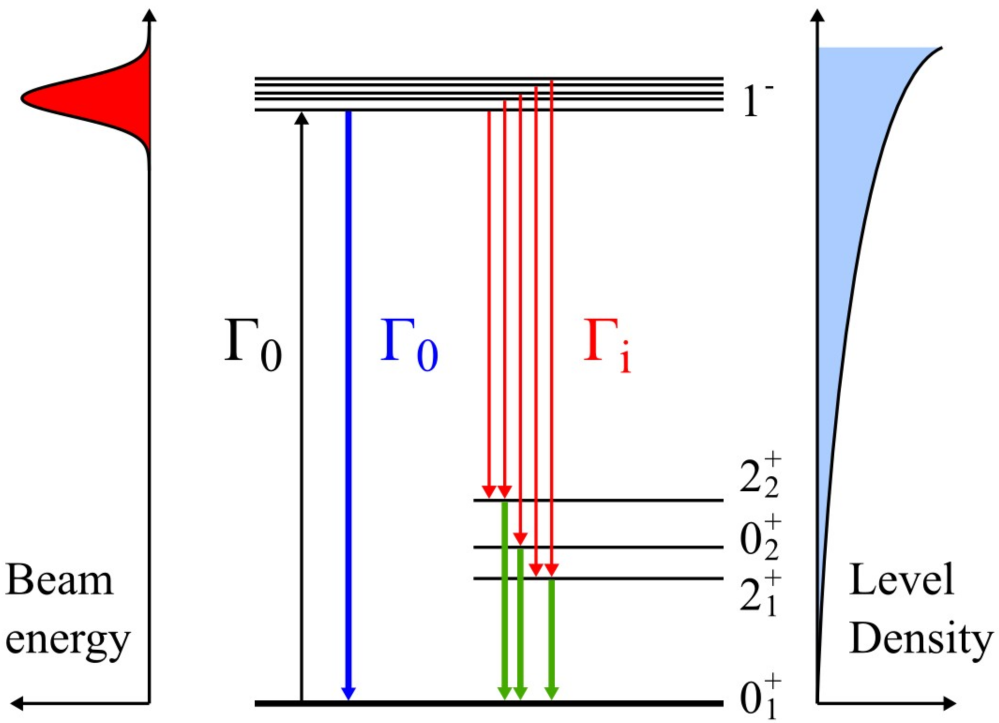
The γ^3 setup



- Decay „elastic“ (Γ_0) or „inelastic“ (Γ_i)
- Elastic channel dominant: (Γ_0 » Γ_i)
- Select low energy decay

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

The γ^3 setup



High level density
→ Use high resolution HPGe

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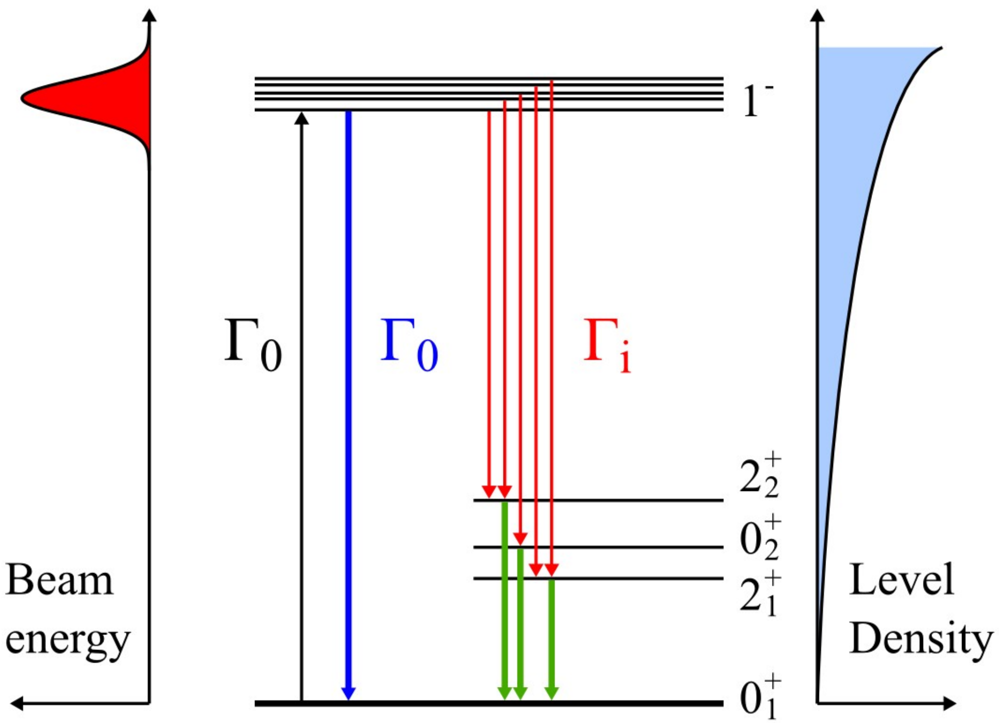
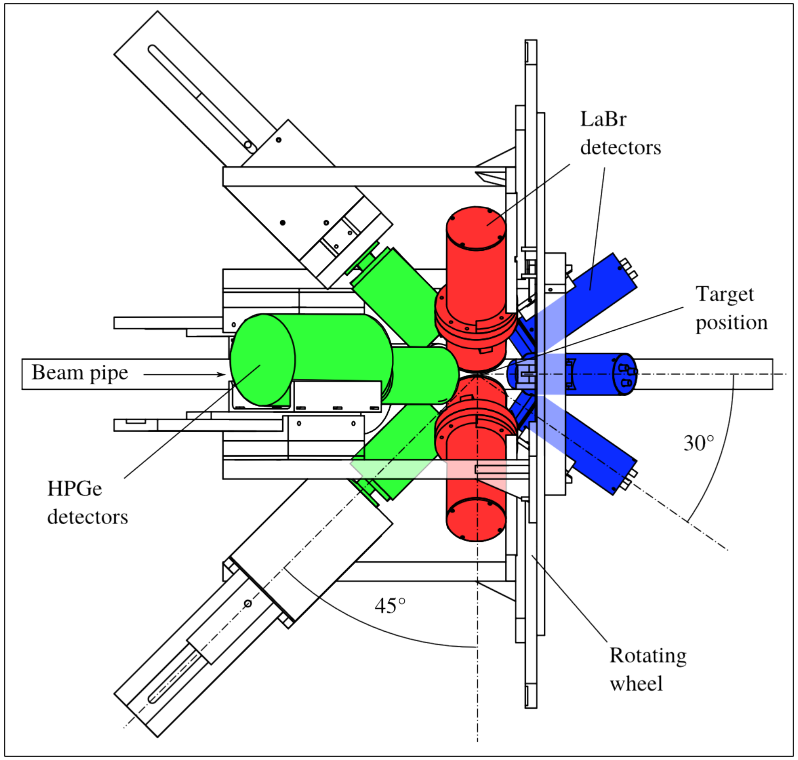


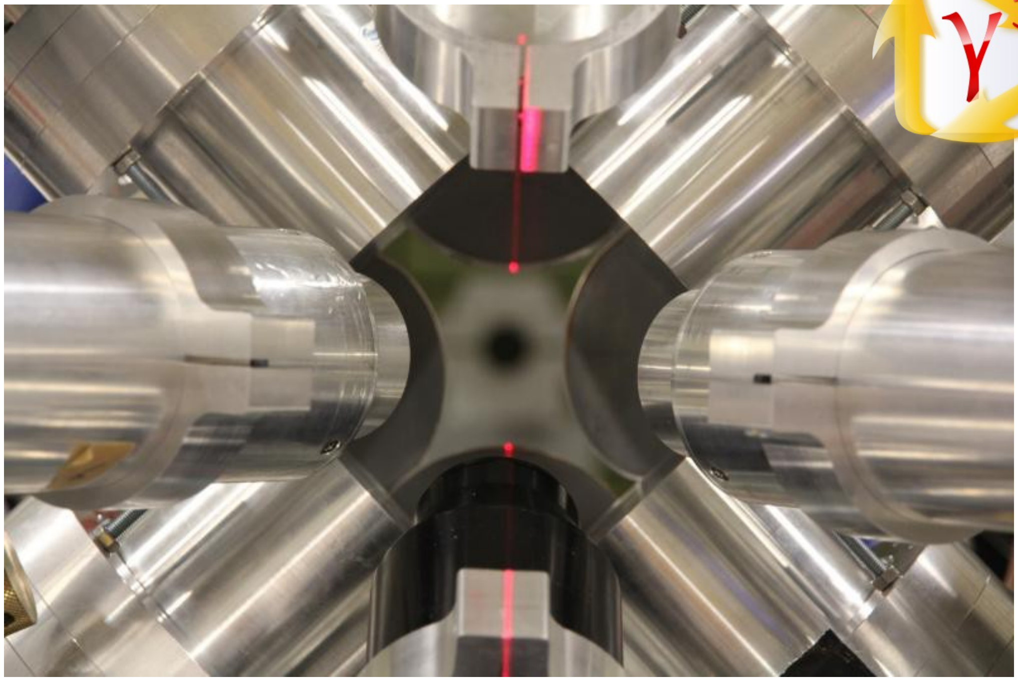
High level density
→ Use high resolution HPGe

Low level density
→ Use high efficiency LaBr

- Combine HPGe with LaBr detectors

The γ^3 setup





New detector array at HIγS

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

B. Löher *et al.*,
Nucl. Instr. Meth. A (2013),
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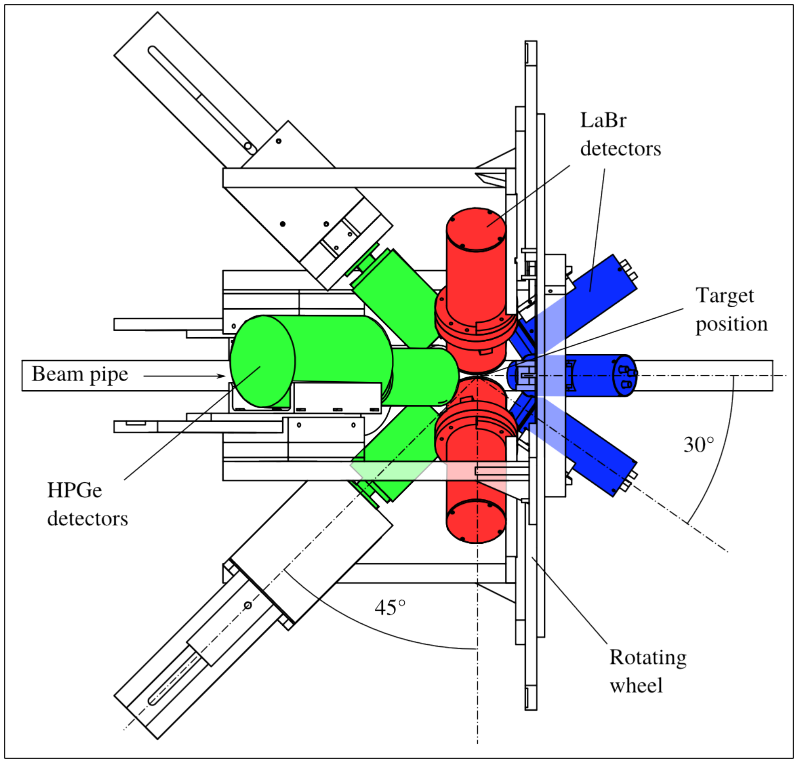
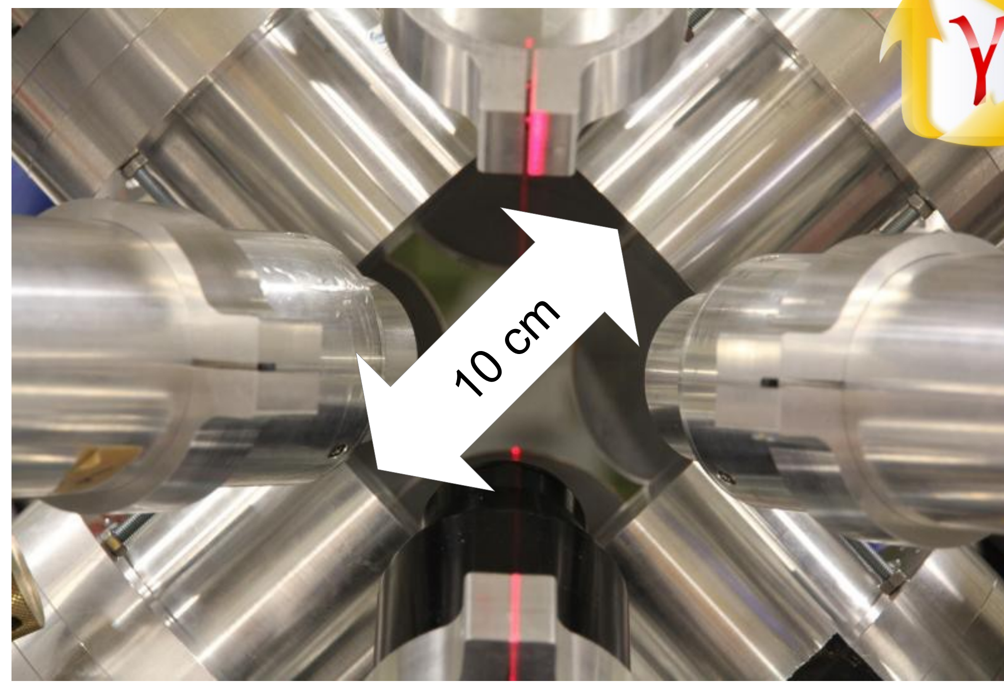
The γ³ setup





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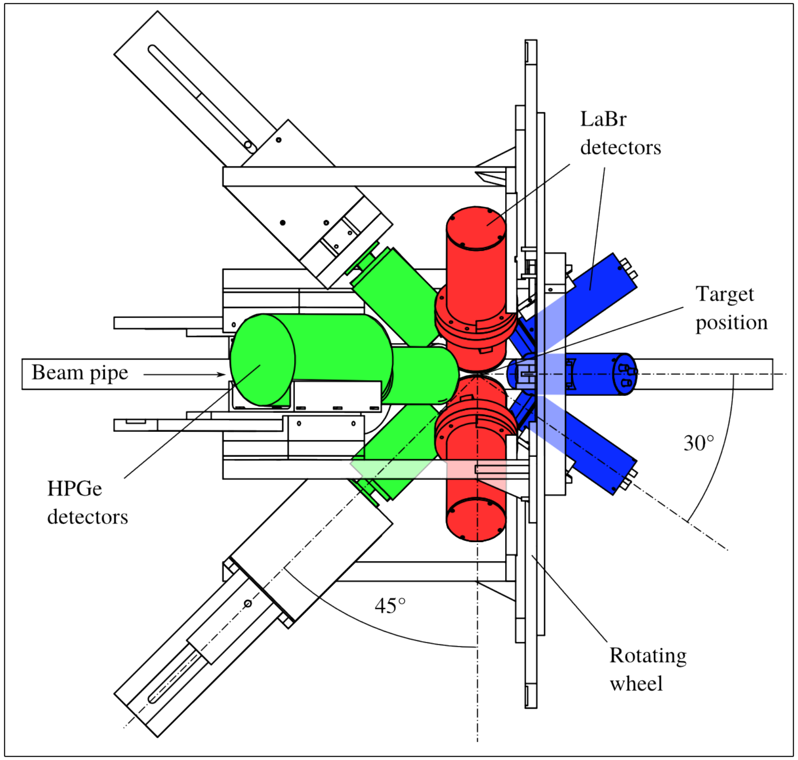

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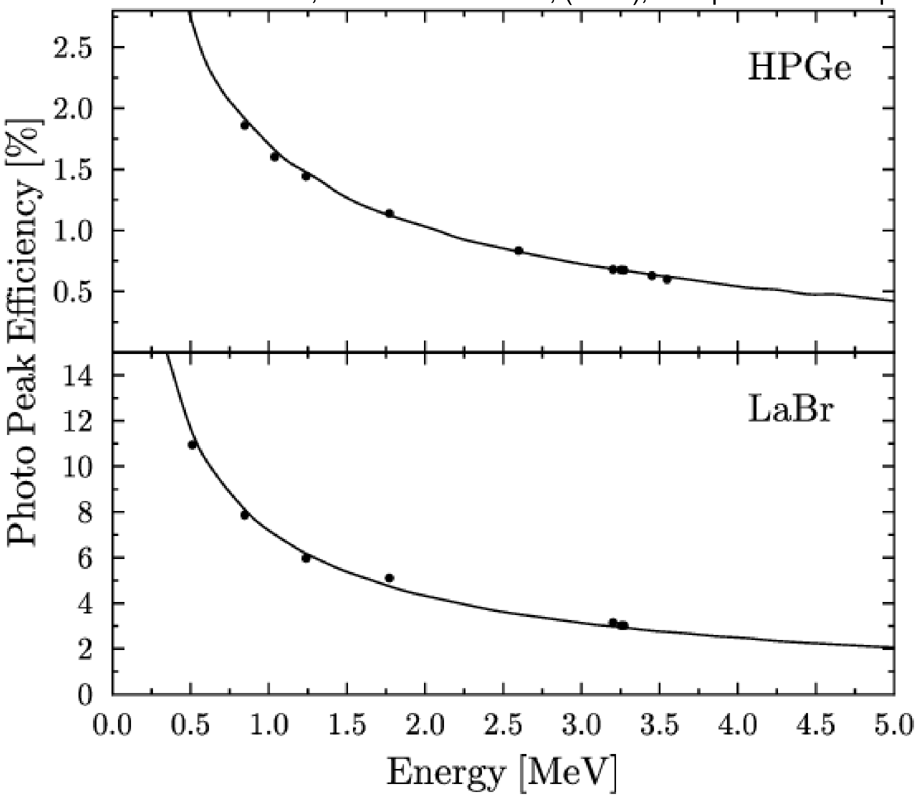
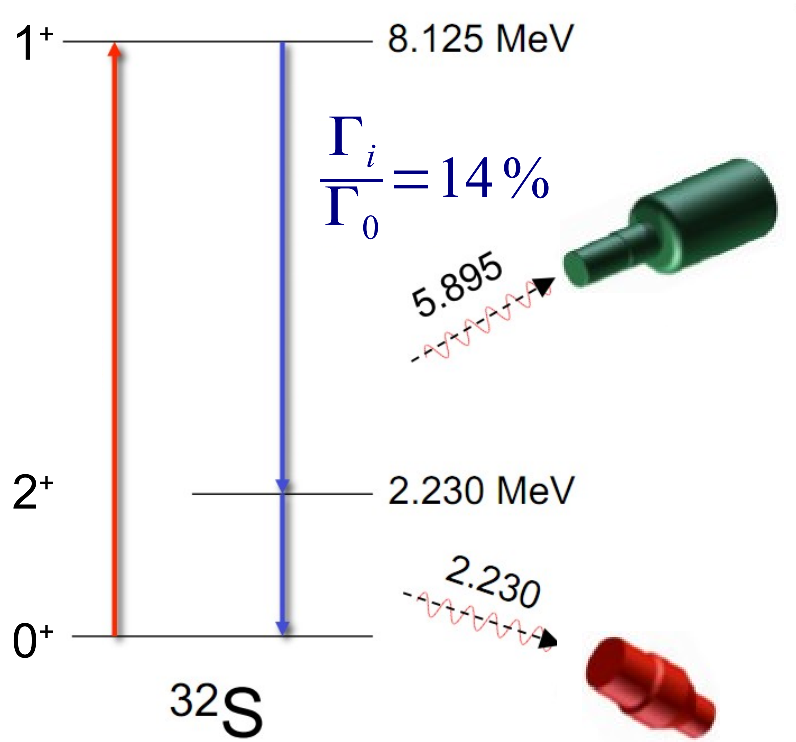


New detector array at HIγS

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

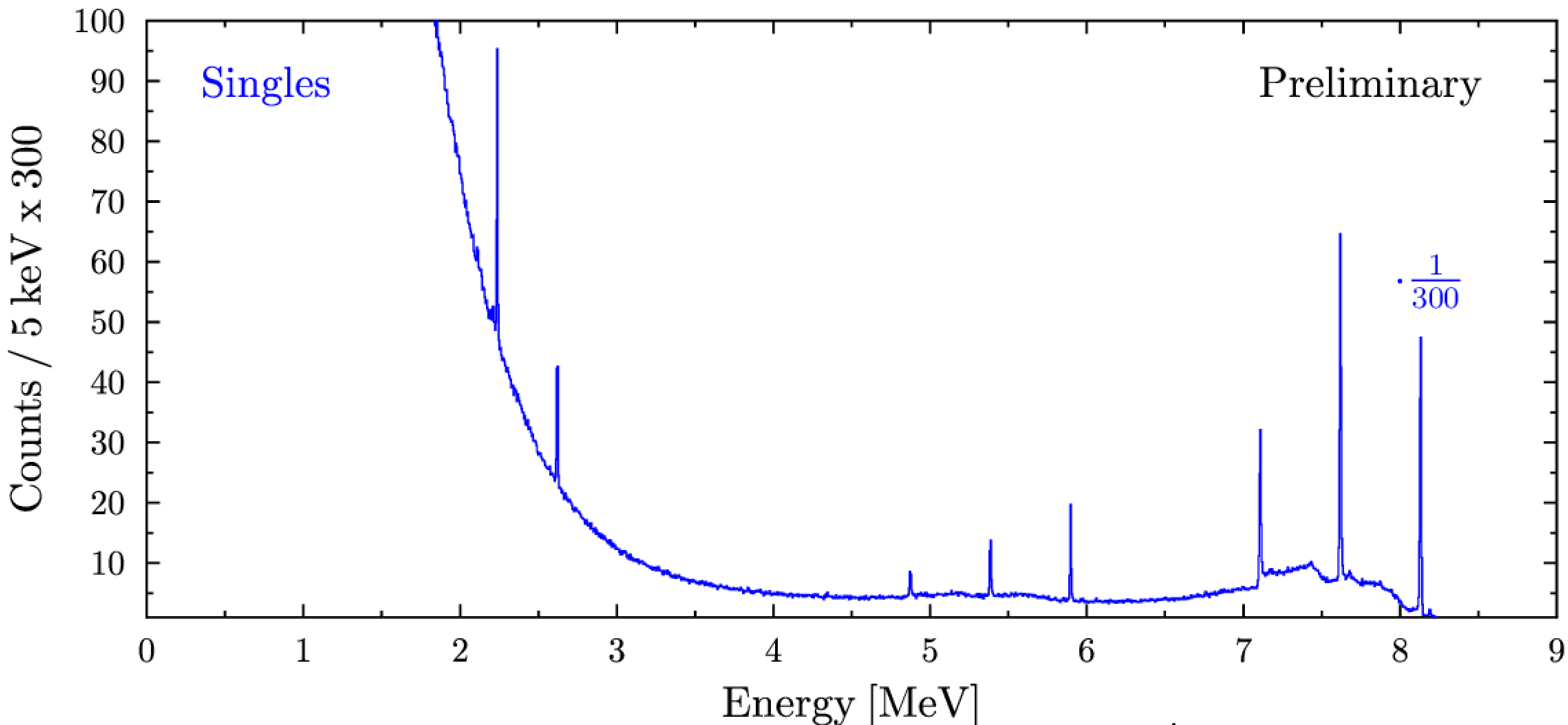
Setup Commissioning

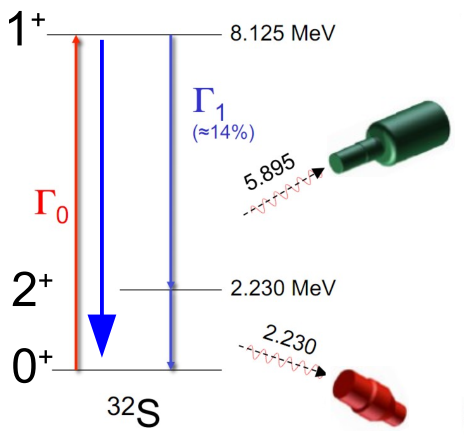


Full setup with 4x HPGe (60%) + 4x 3“x3“ LaBr

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

Setup Commissioning





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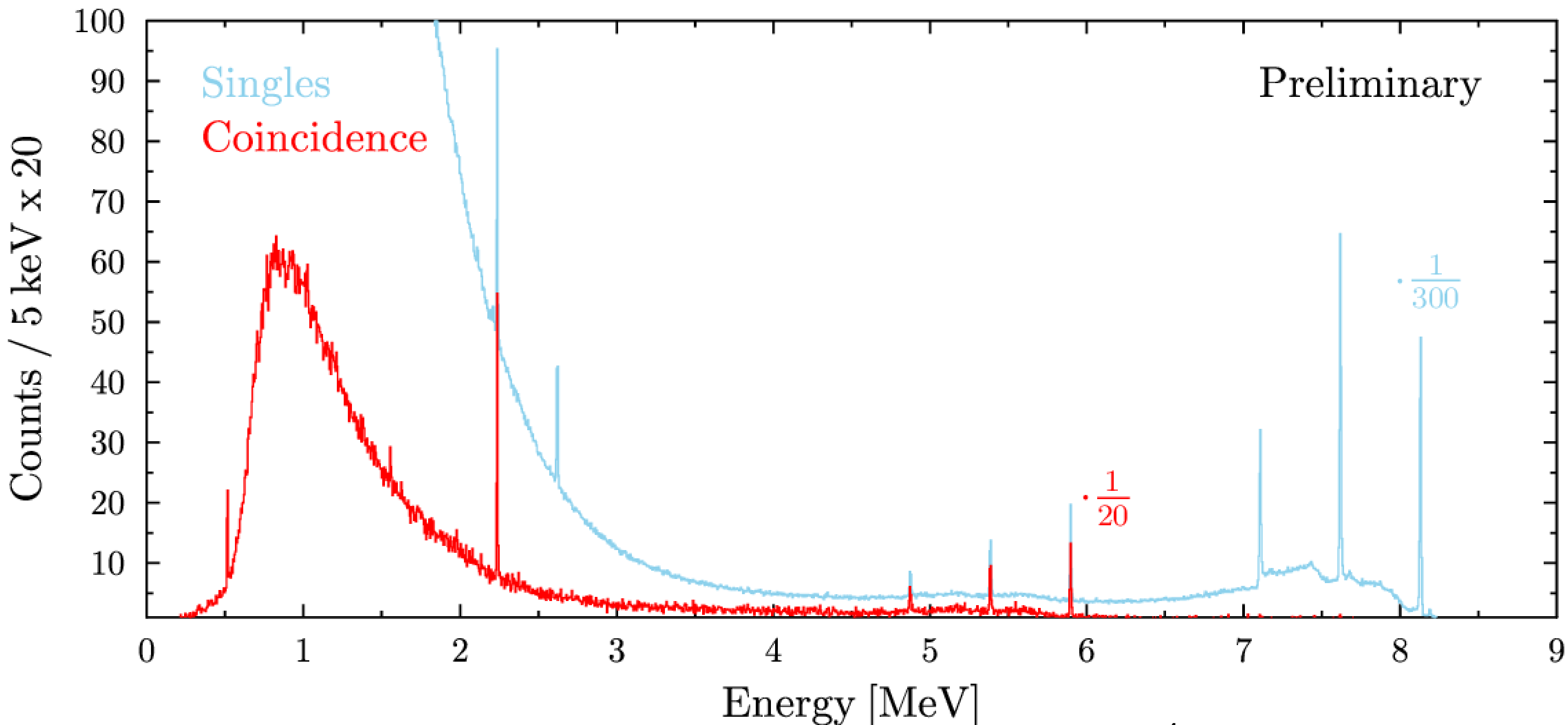

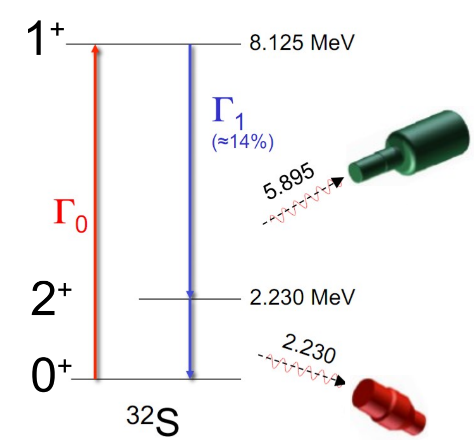

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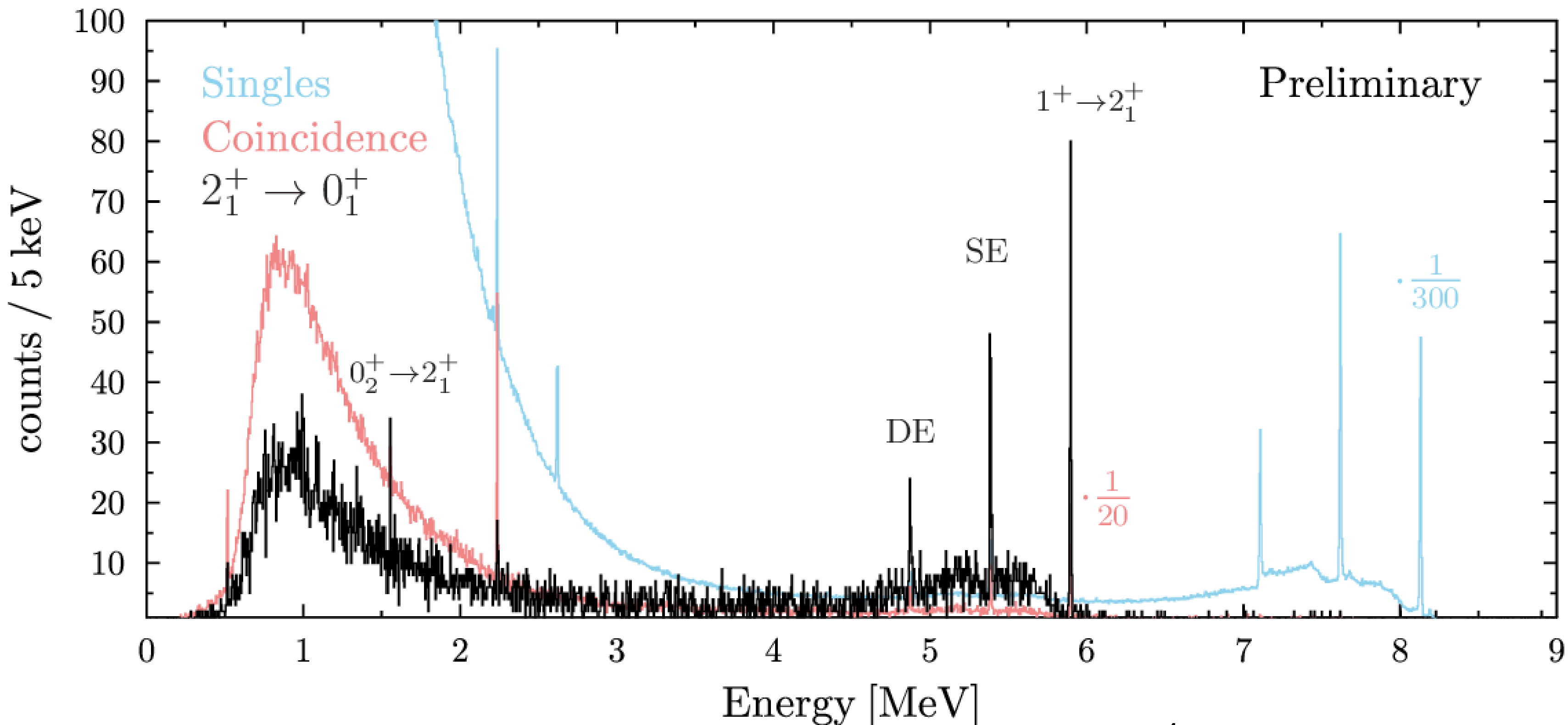
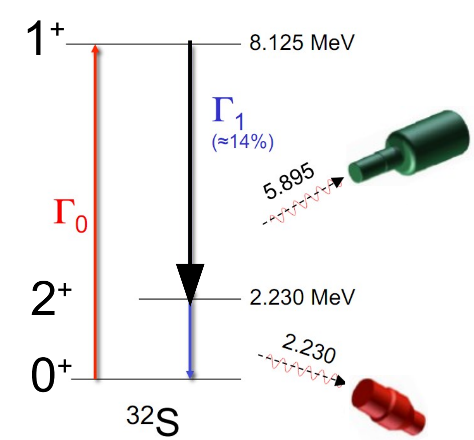


Peak to Background:

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



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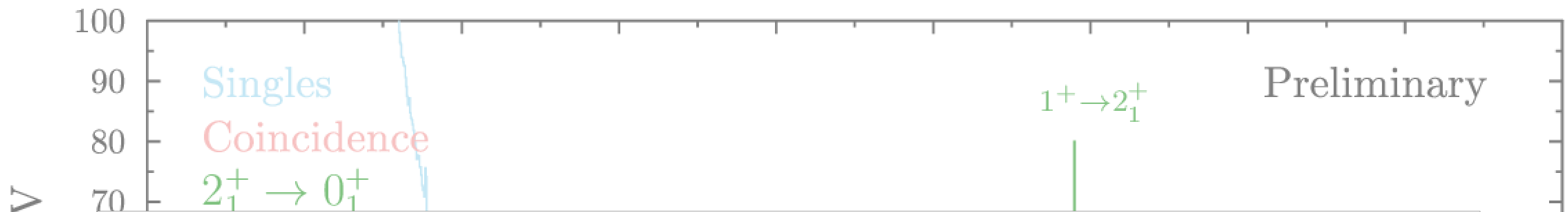

Results

E_γ	b_0 (%)				$b_{0,a}$	$b_{0,b}$
(keV)	HPGe–LaBr[a]	LaBr–LaBr[b]	HPGe[c]	LaBr[d]	(%)	(%)
8124	100	100	100	100	100	100
5894	16.5(14)	15.7(6)	15.7(3)	15.8(1)	16(4)	18(6)

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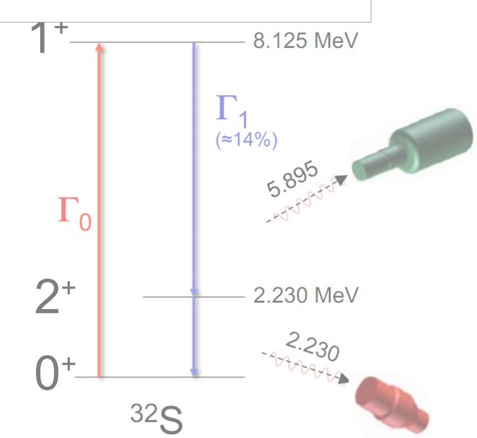
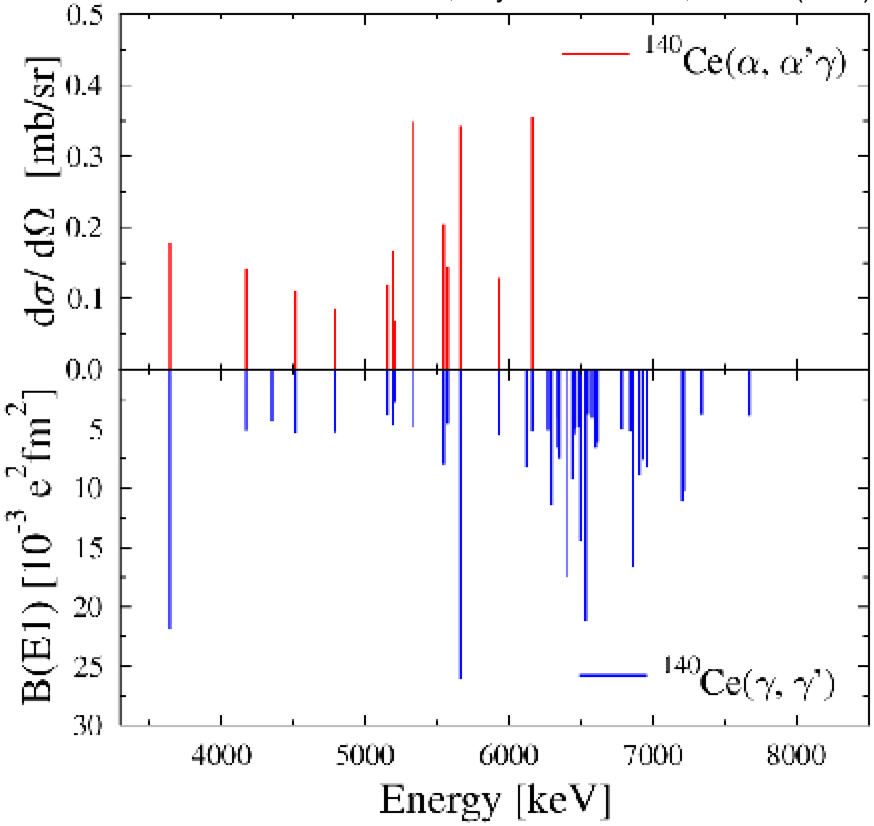


^{140}Ce (γ,γ')

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



Experiment at HIγS:

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

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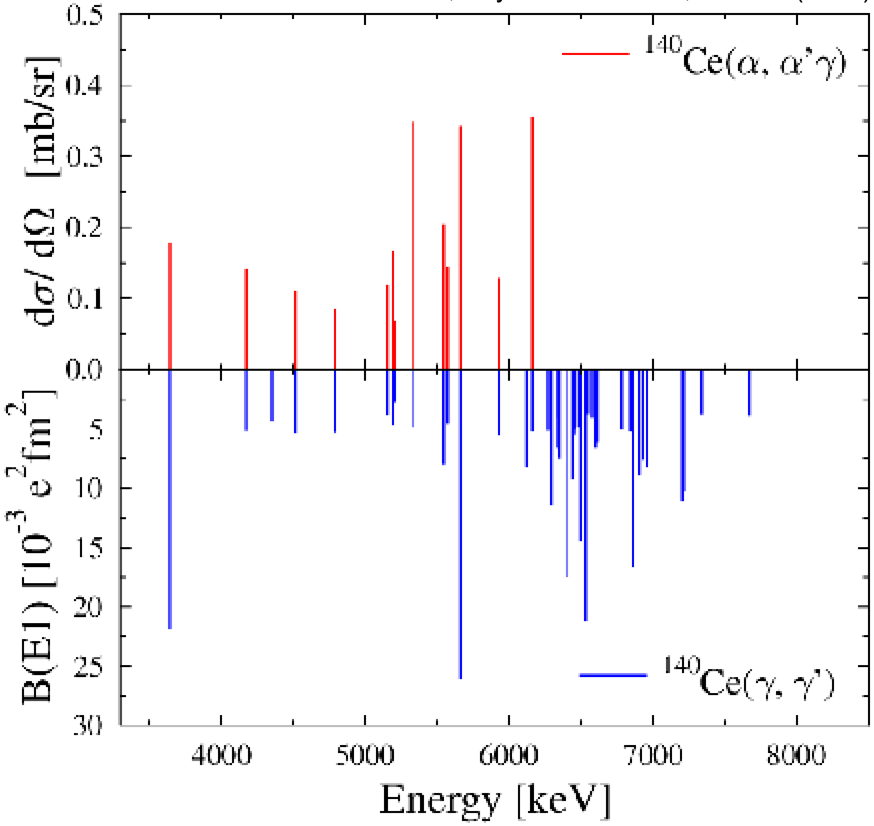

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Splitting of PDR observed with different probes
→ Decay pattern may yield additional information

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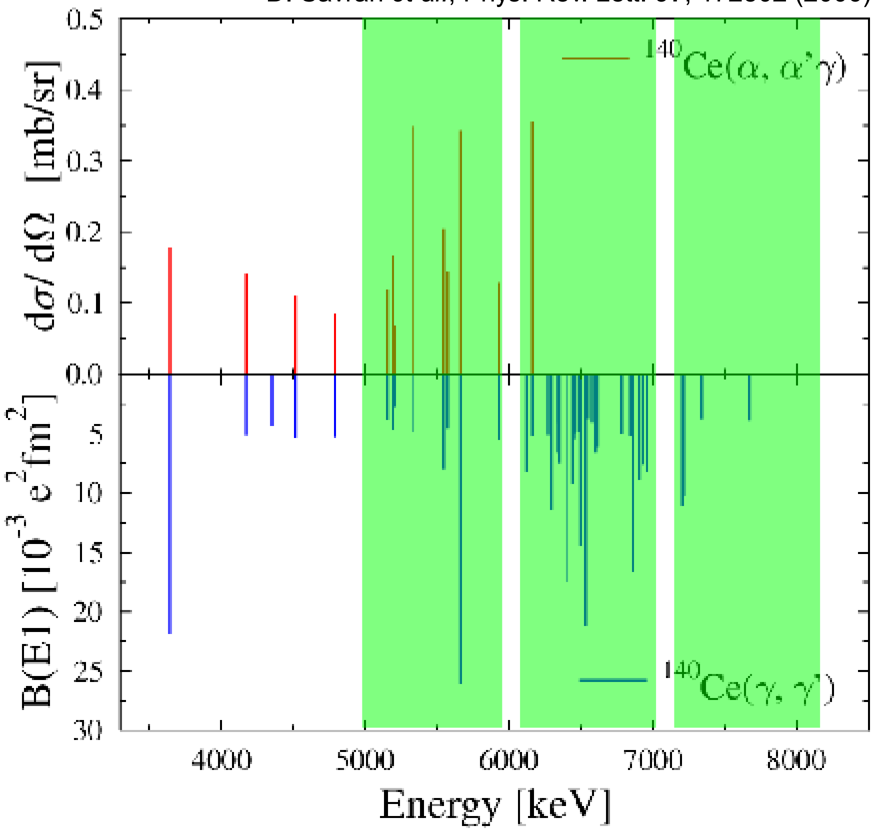

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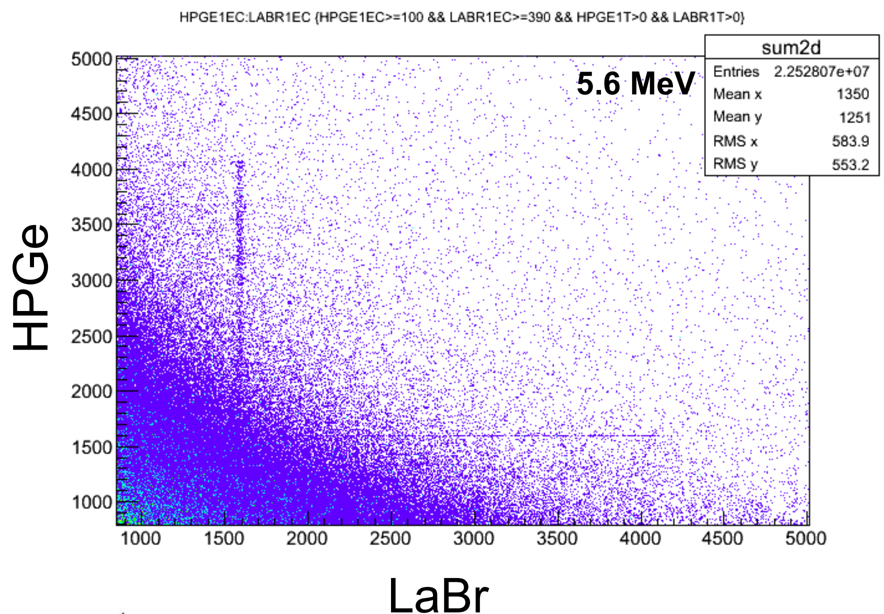

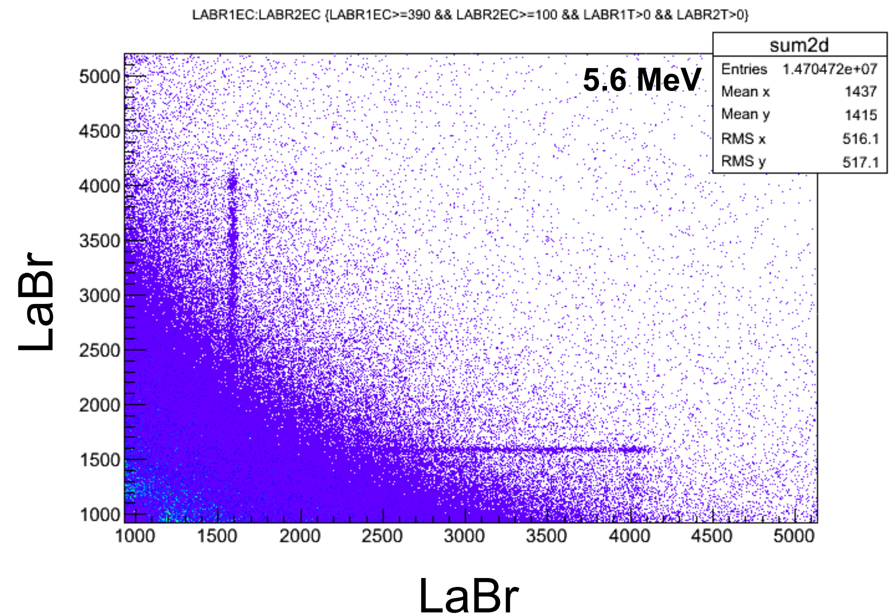

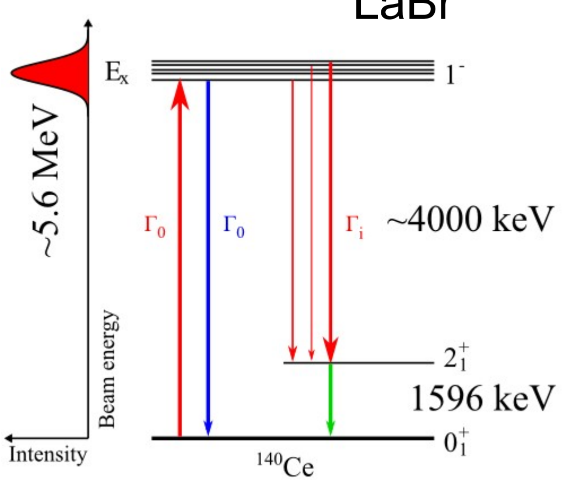

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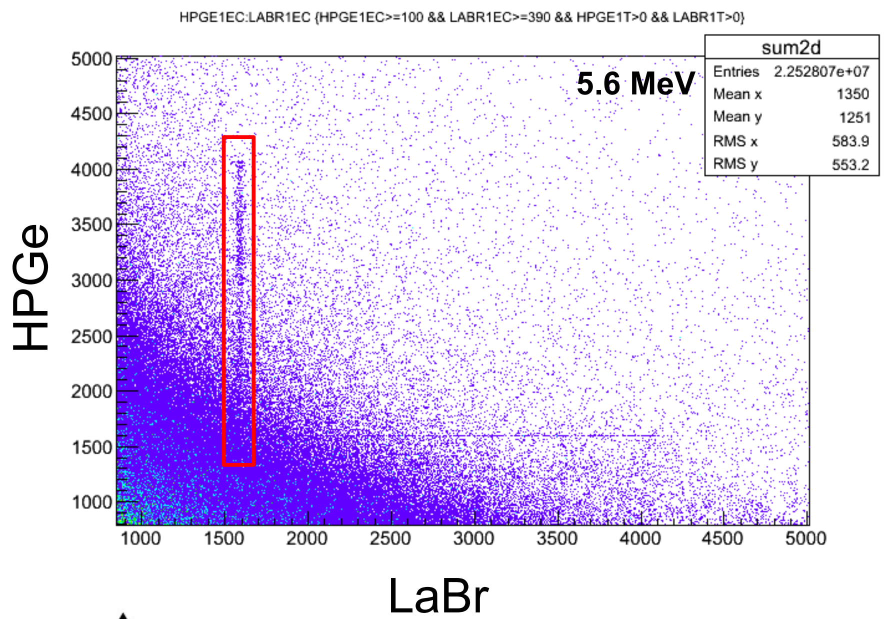
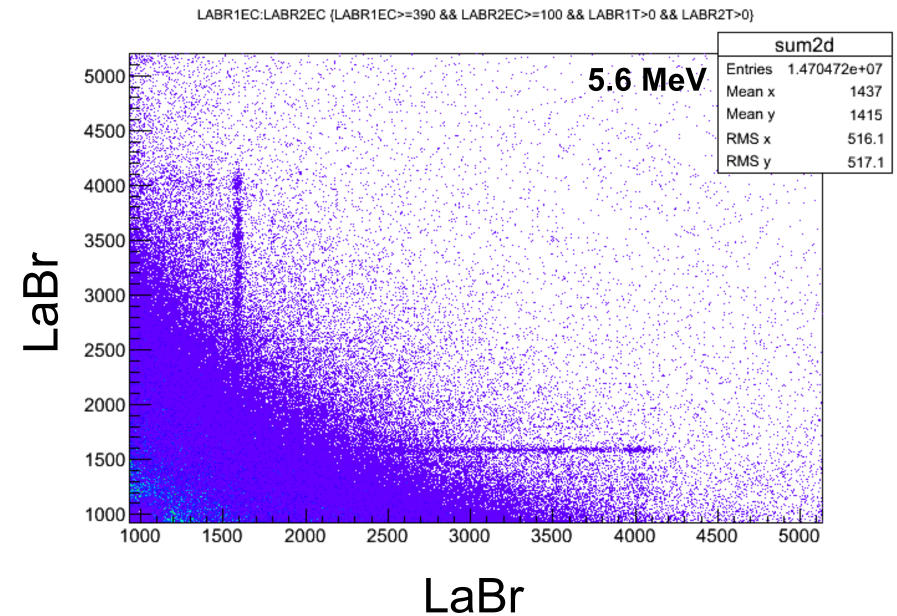
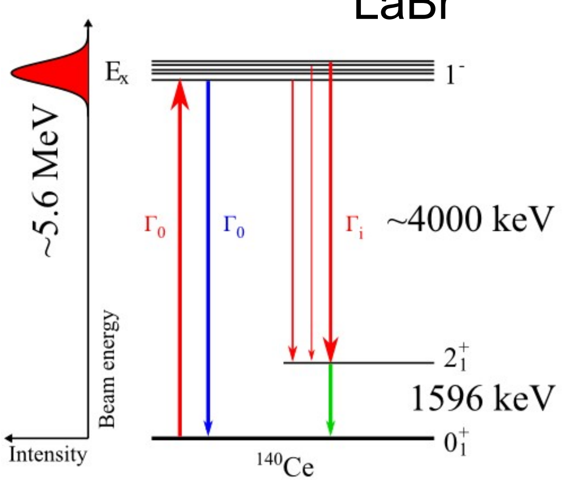




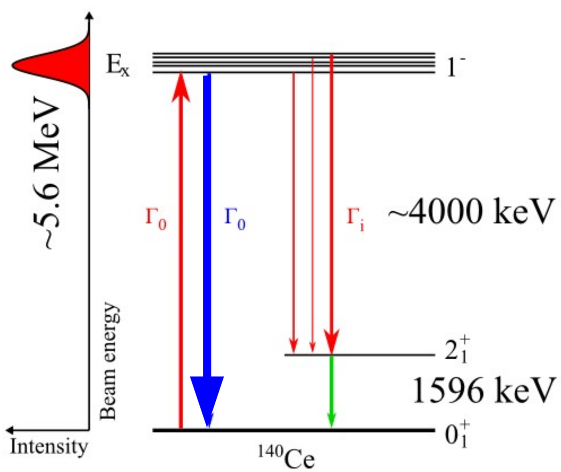


3 possible analyses:

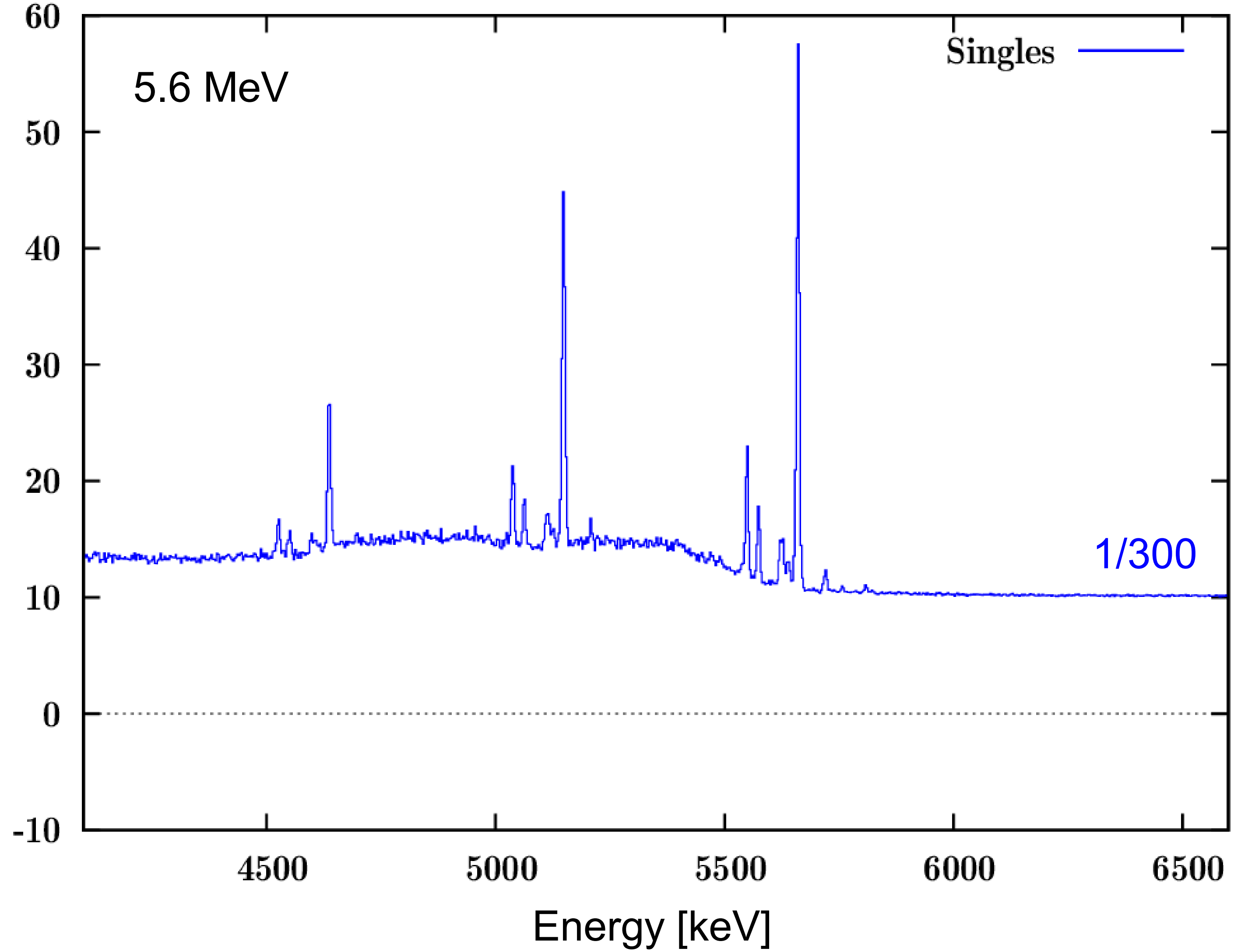
- Gate on $2^+_1 \rightarrow 0^+$ in LaBr:
  1) HPGe spectra (high resolution)

^{140}Ce (γ,γ')

Gate on LaBr → HPGe spectra



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



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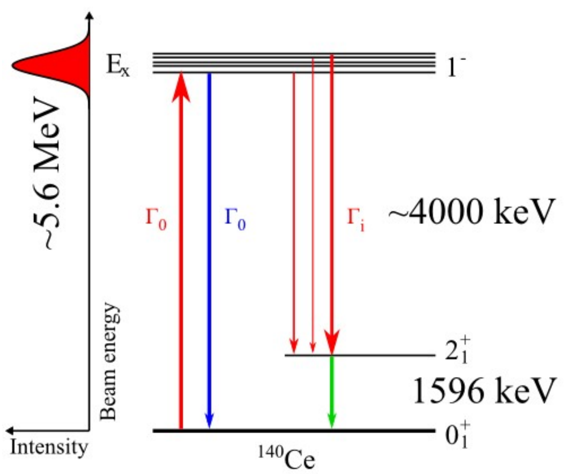

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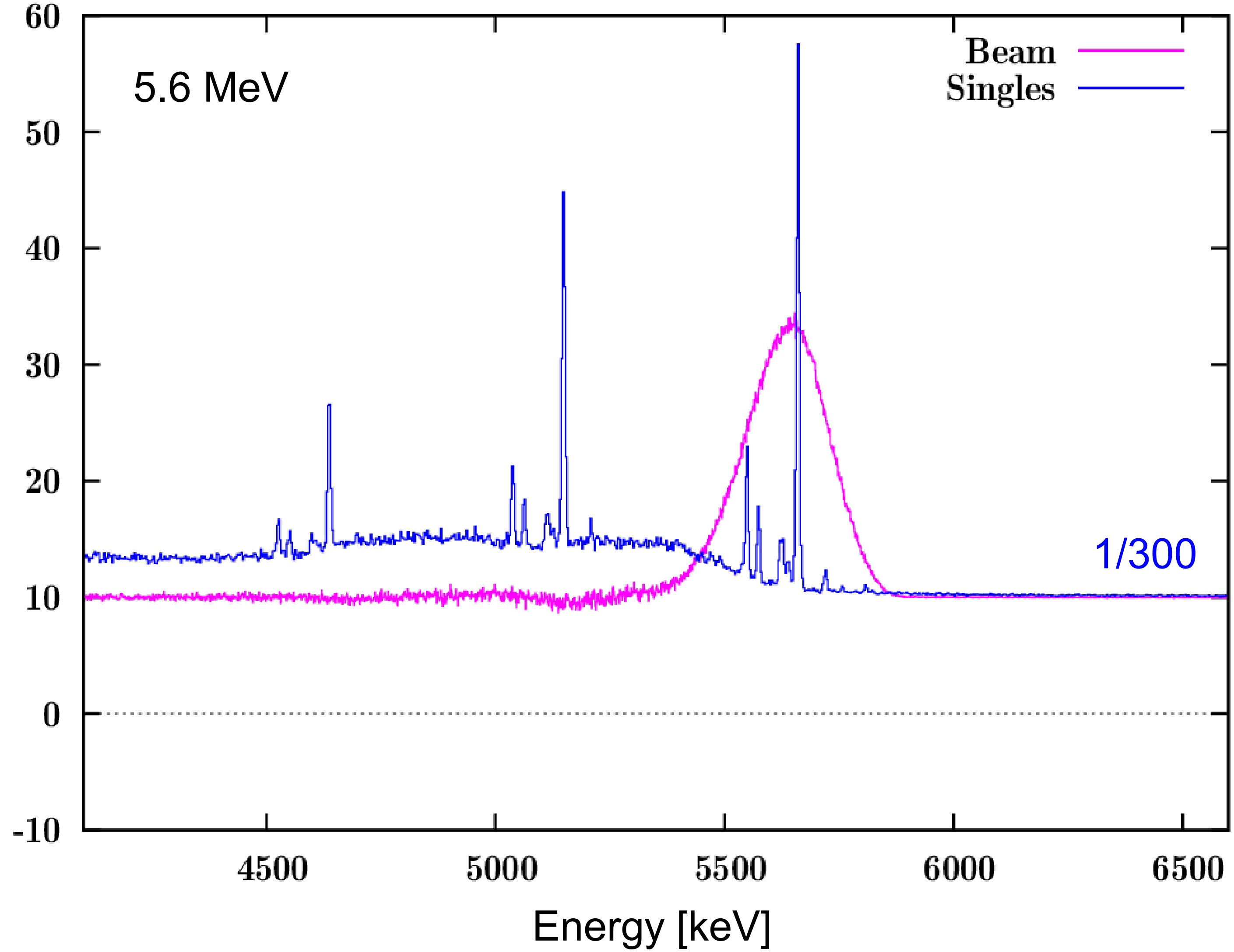

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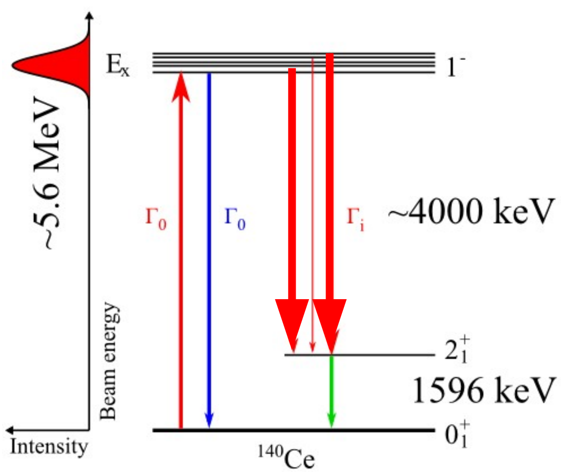

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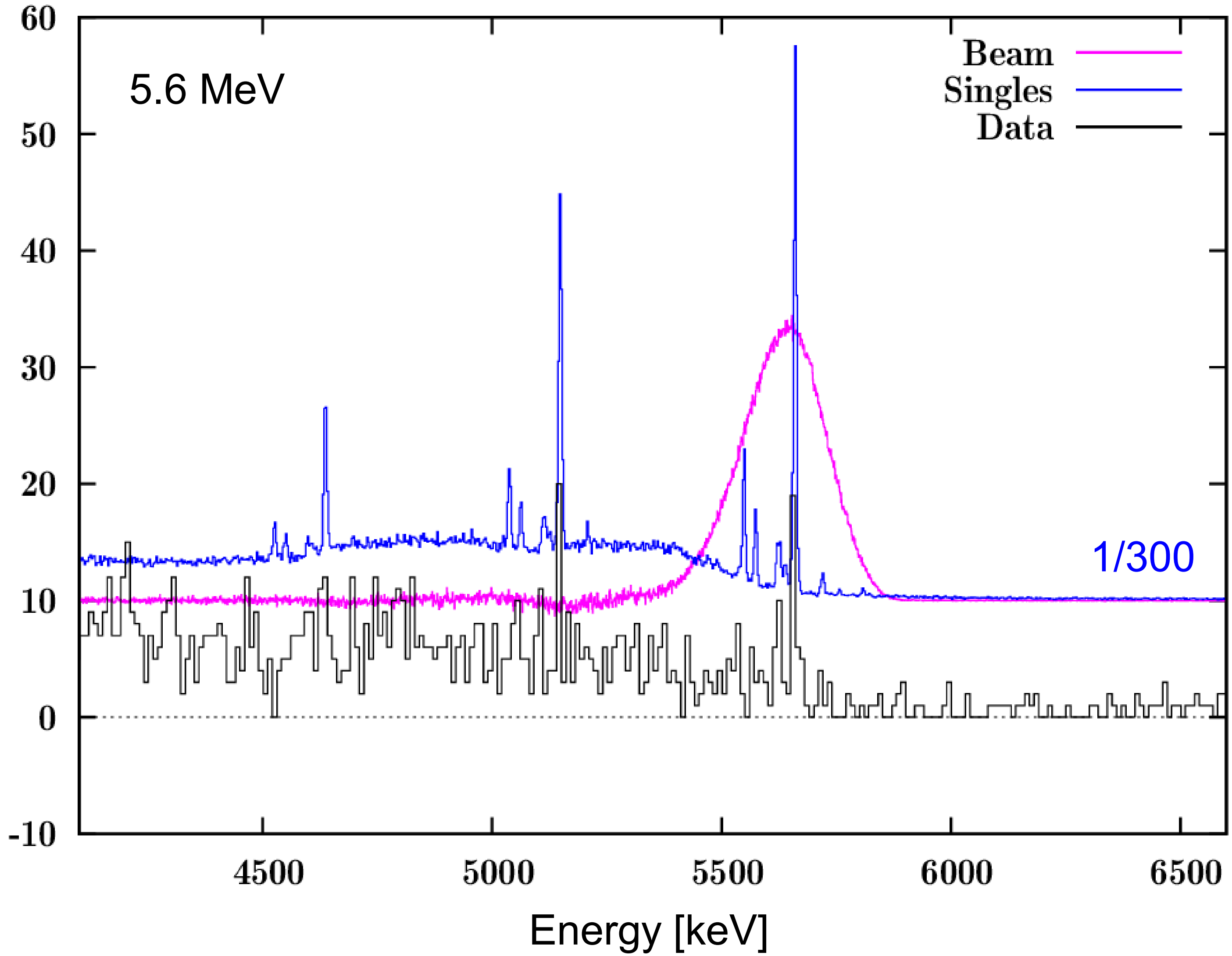

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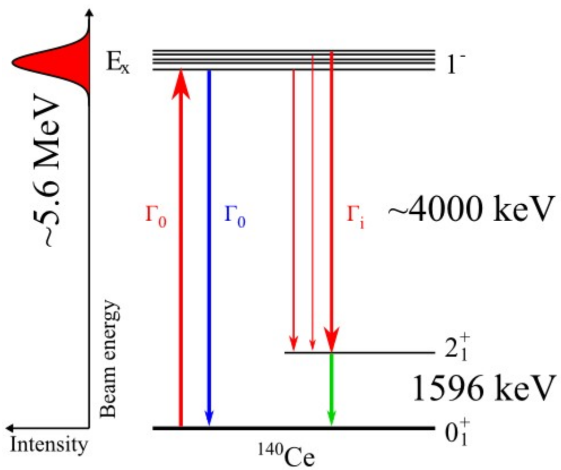

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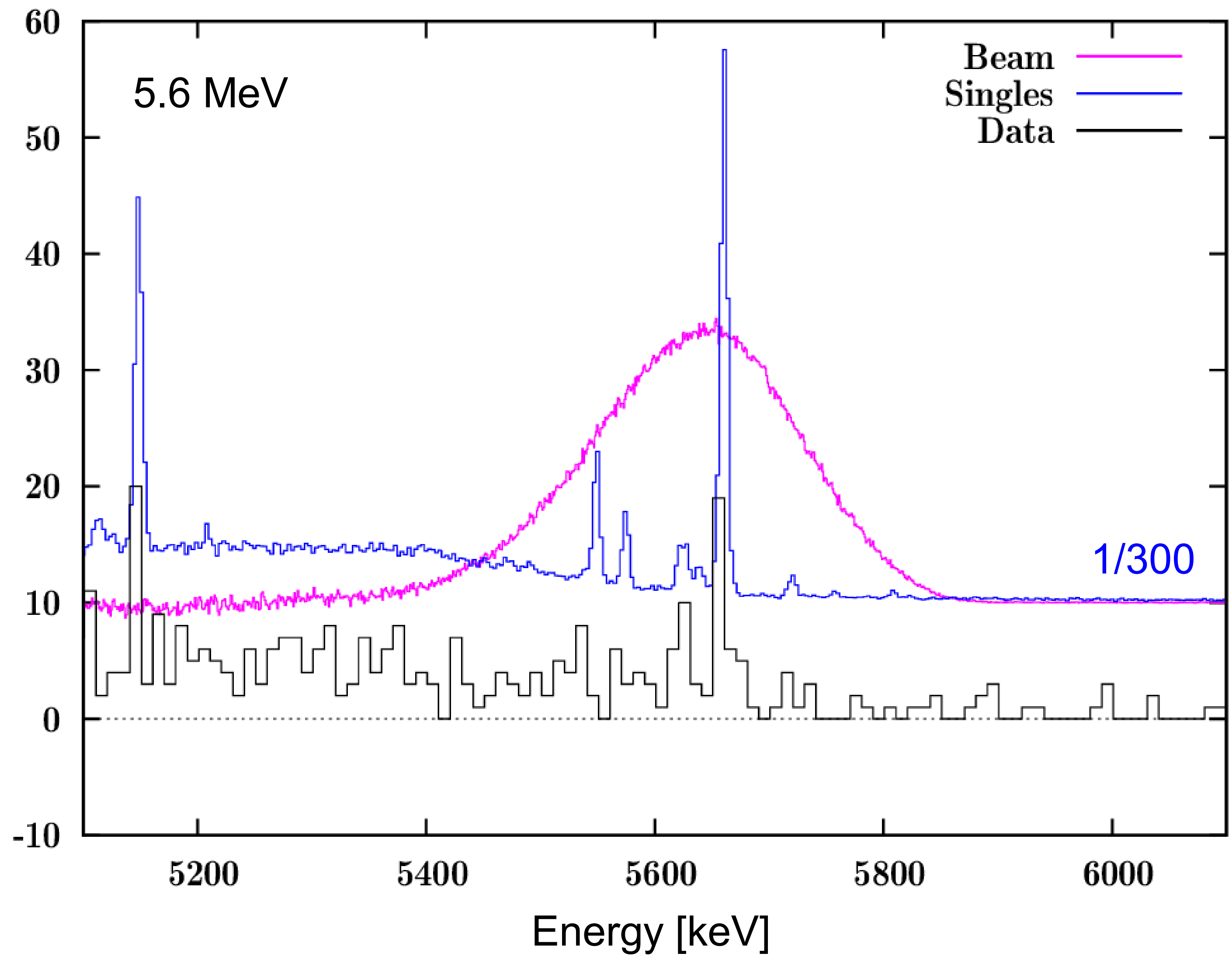

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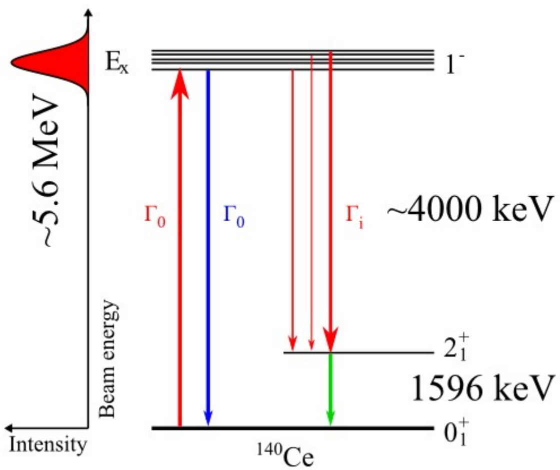

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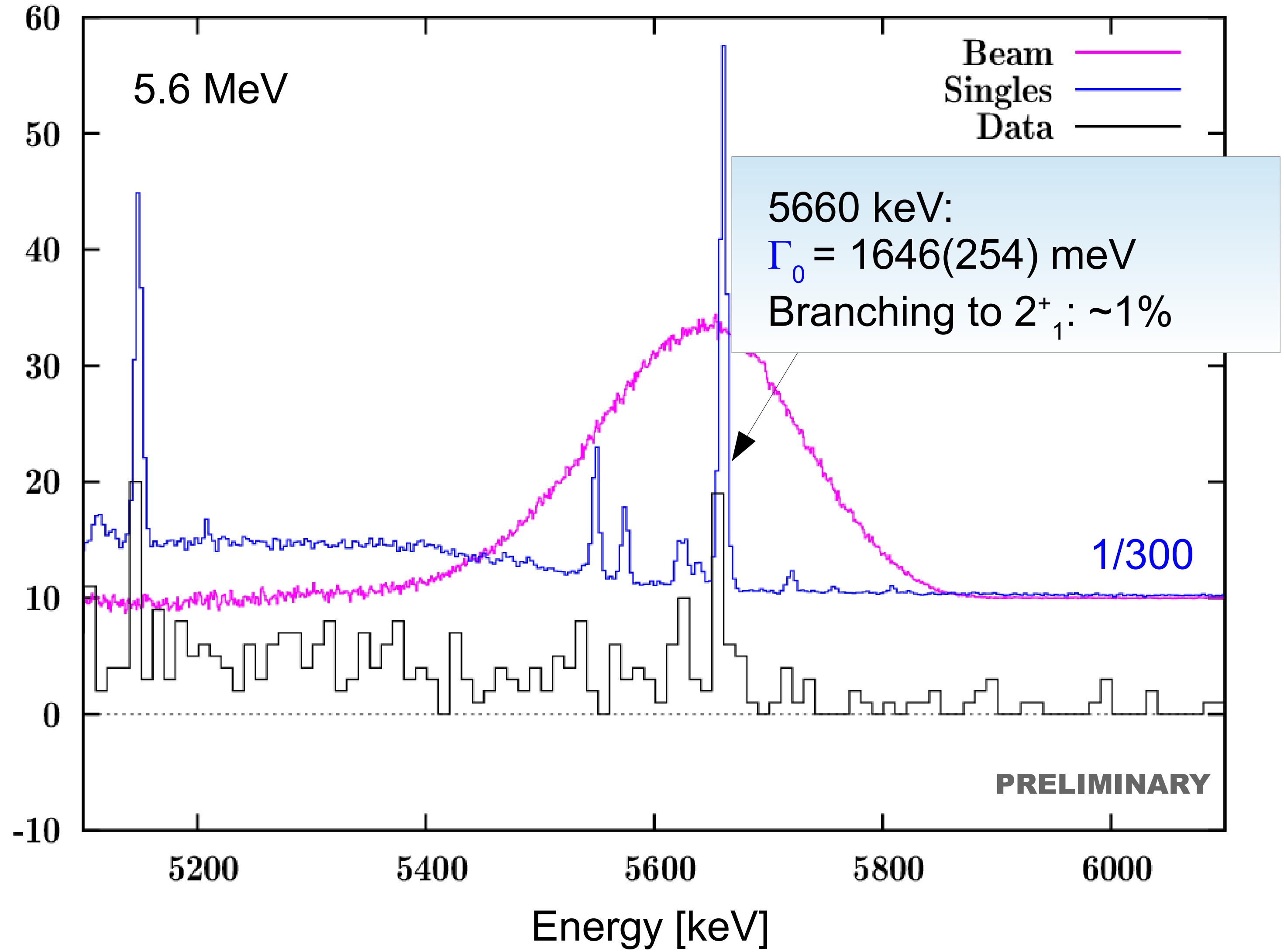

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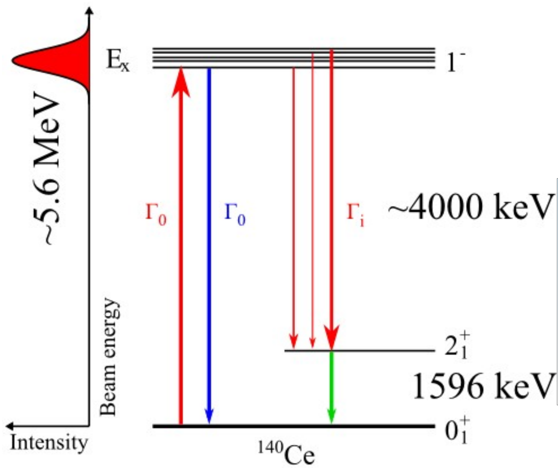

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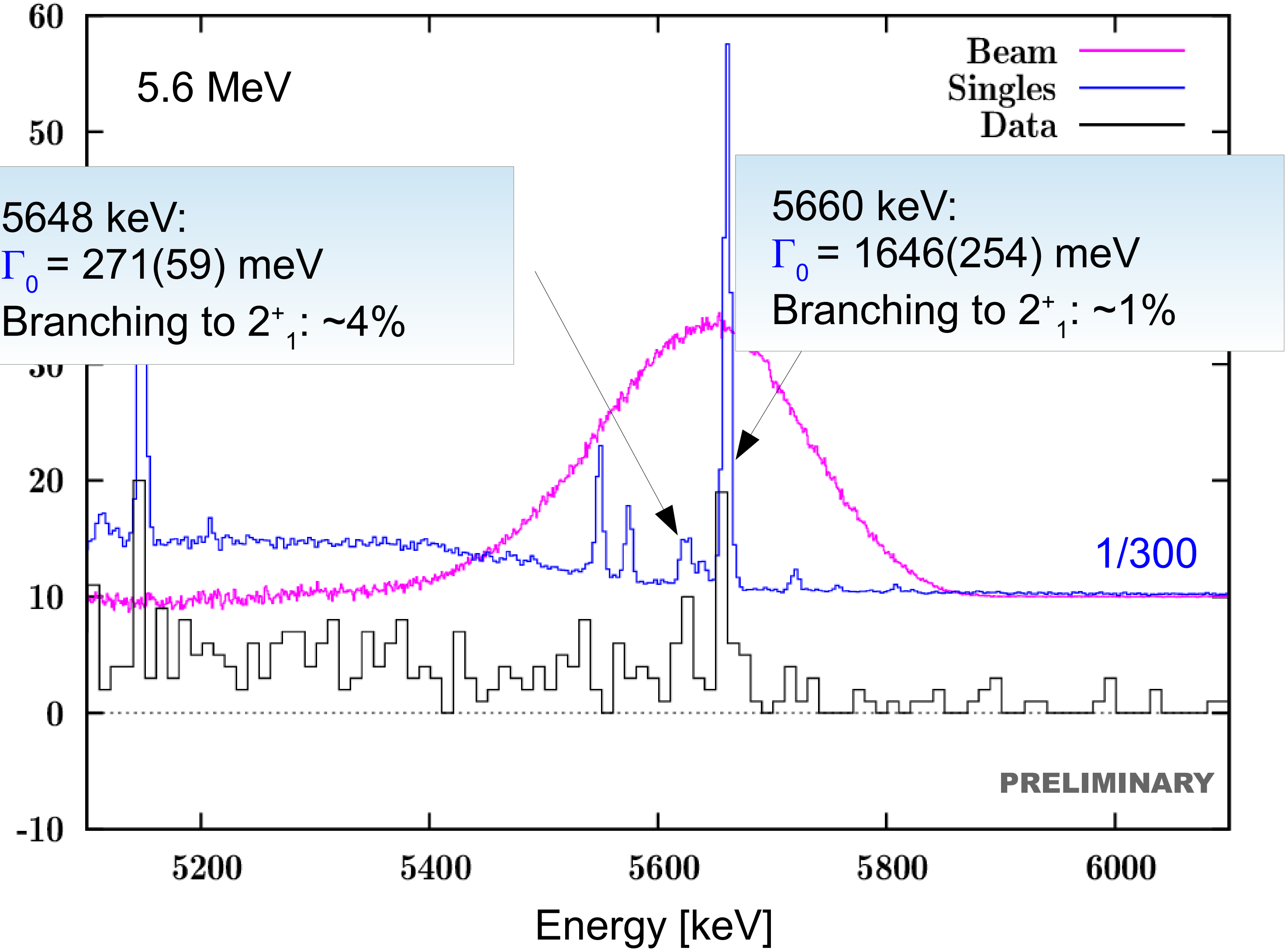

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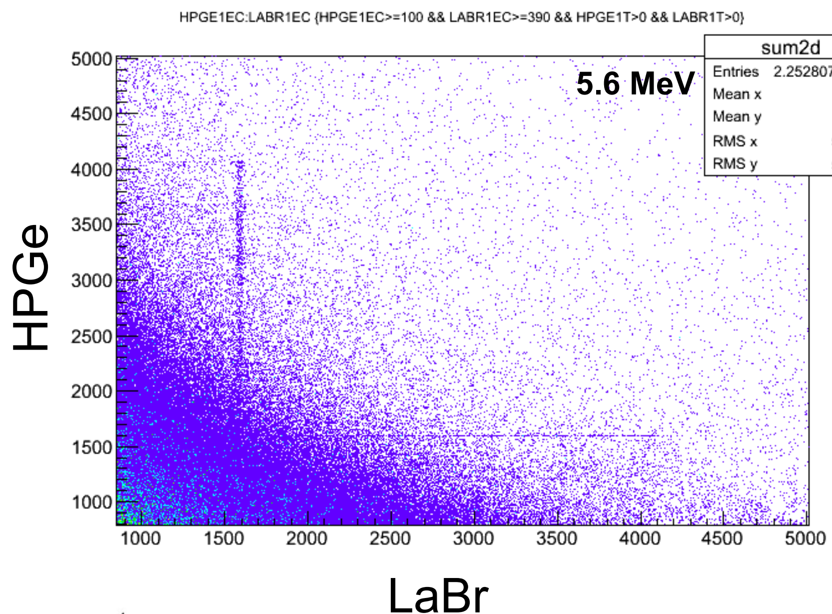

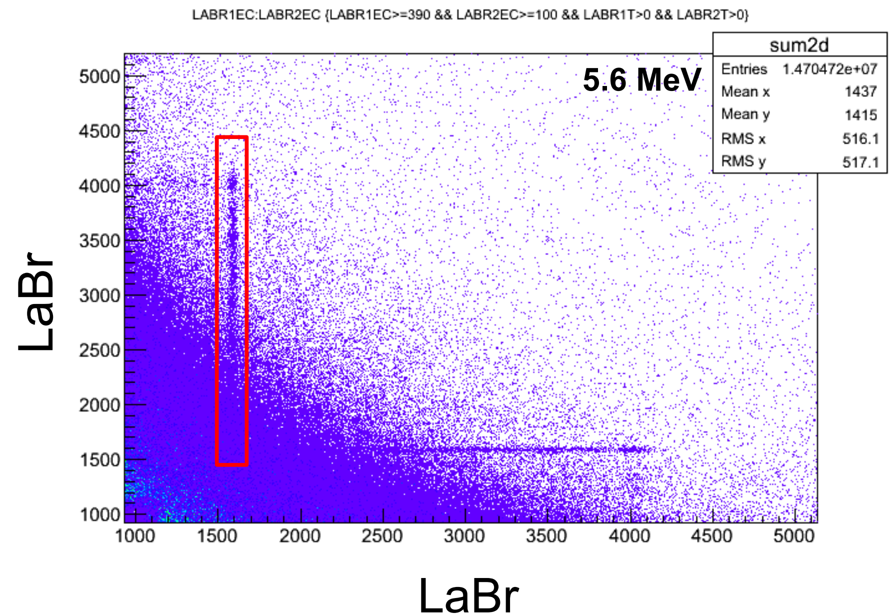

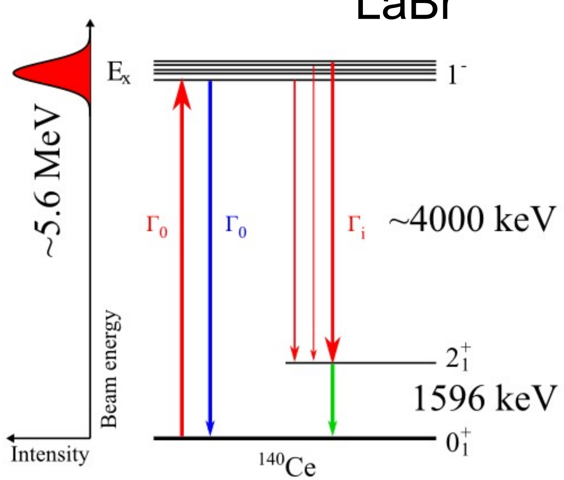

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  2) LaBr spectra (better efficiency)

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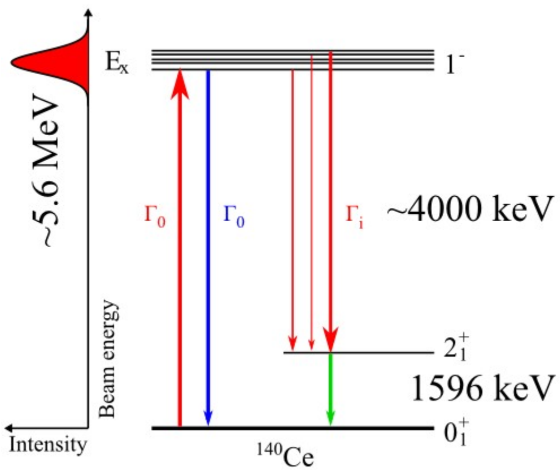
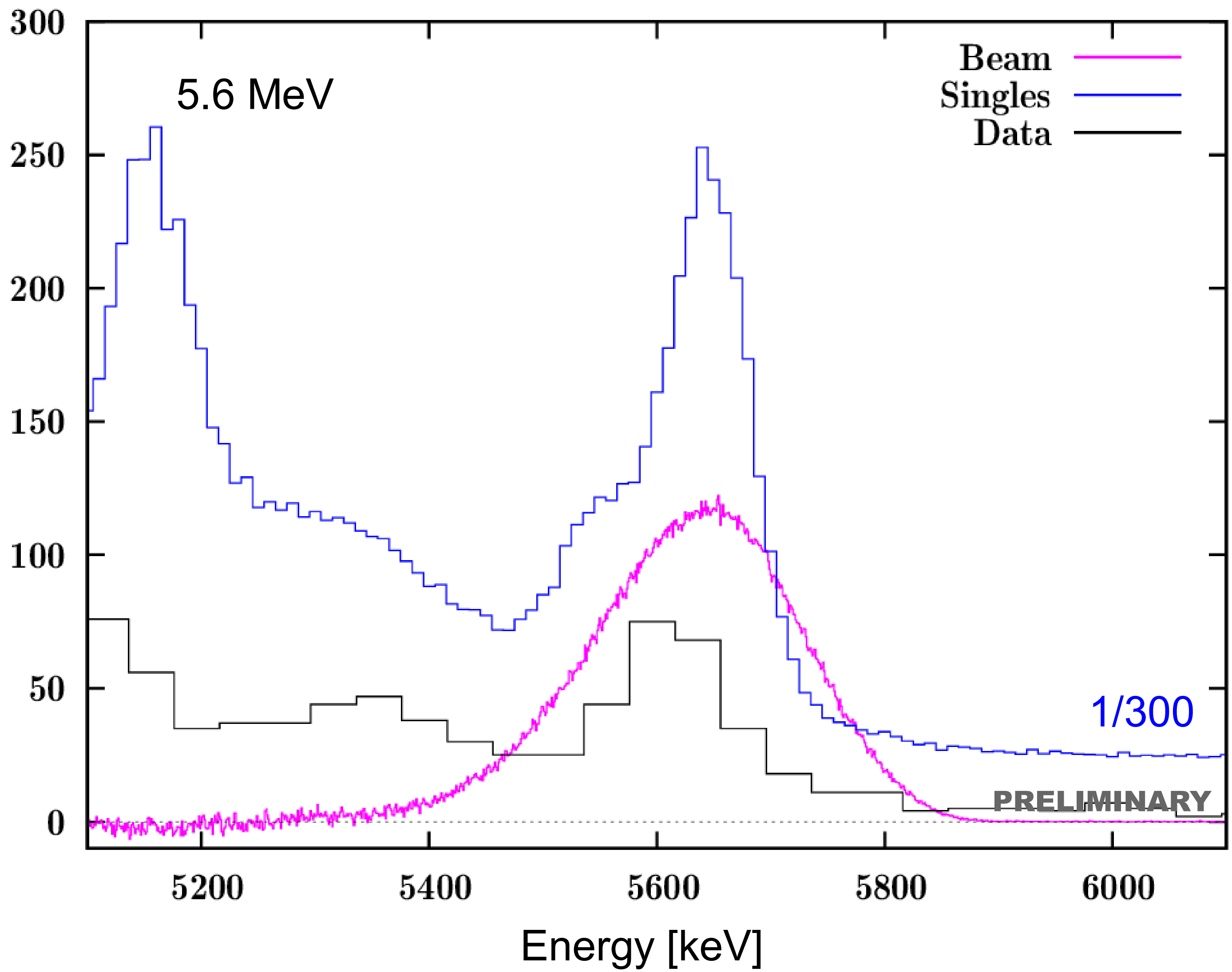
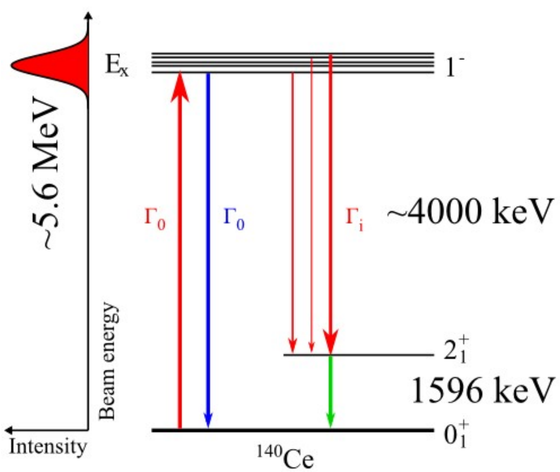


$E(2^+_1) = 1596$ keV

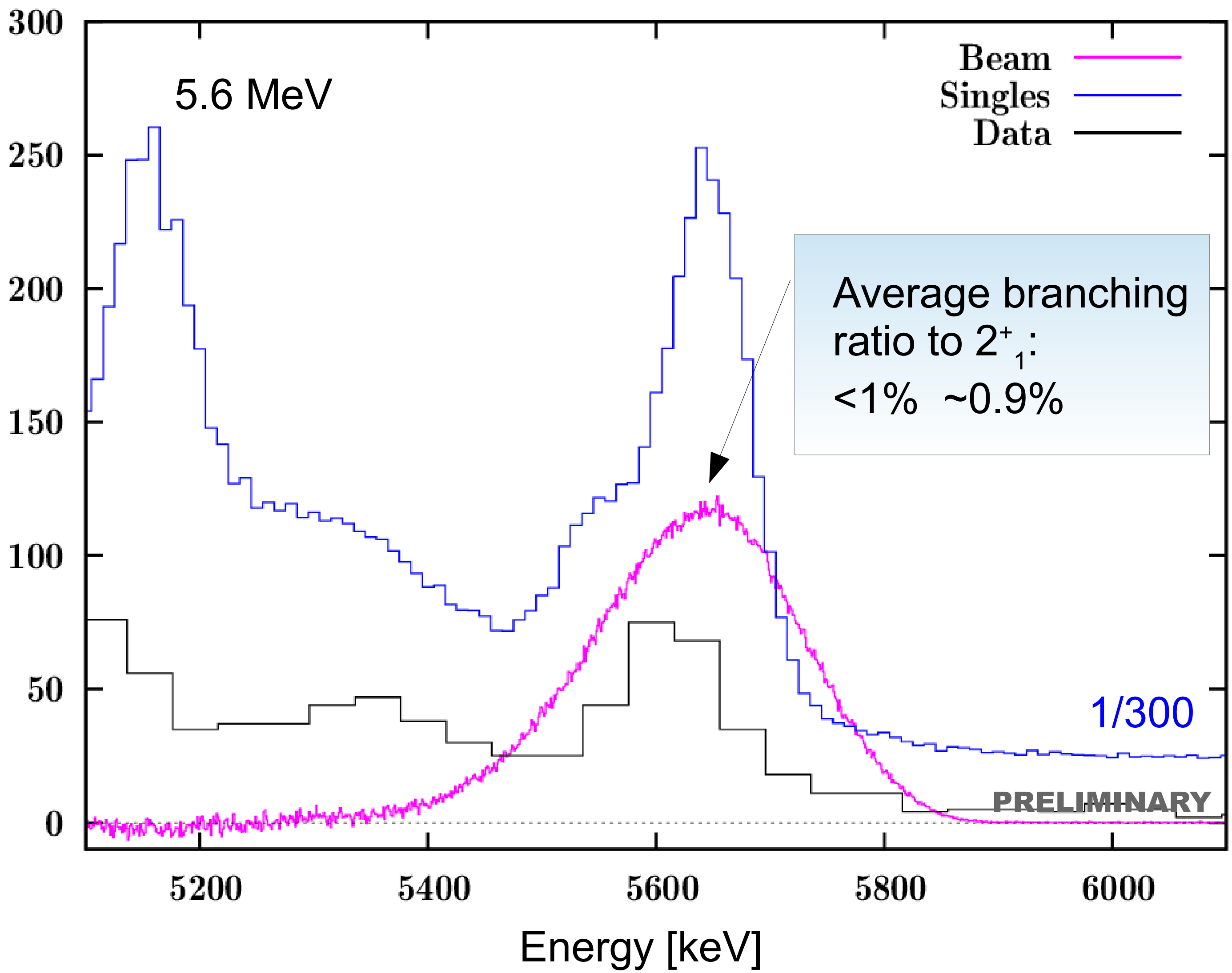


^{140}Ce (γ,γ')

Gate on LaBr → LaBr spectra

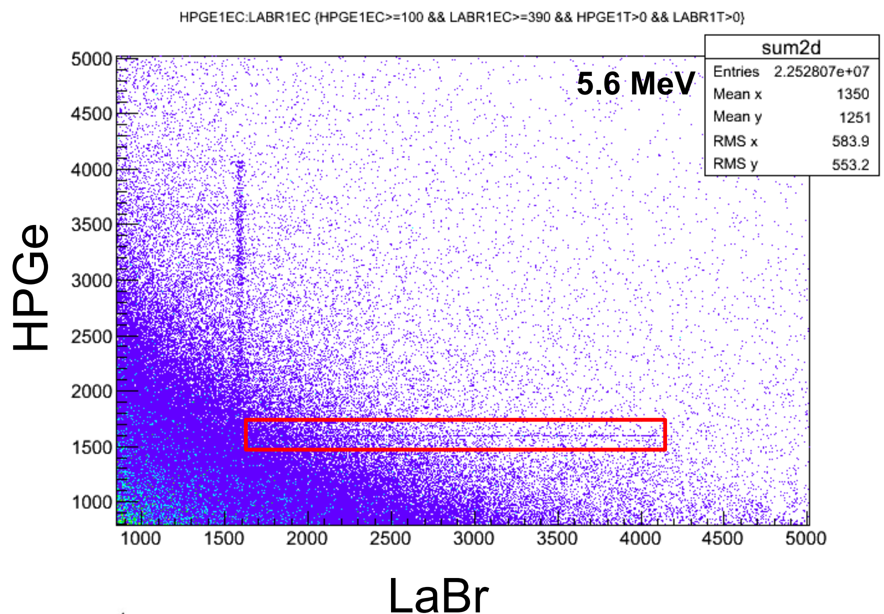


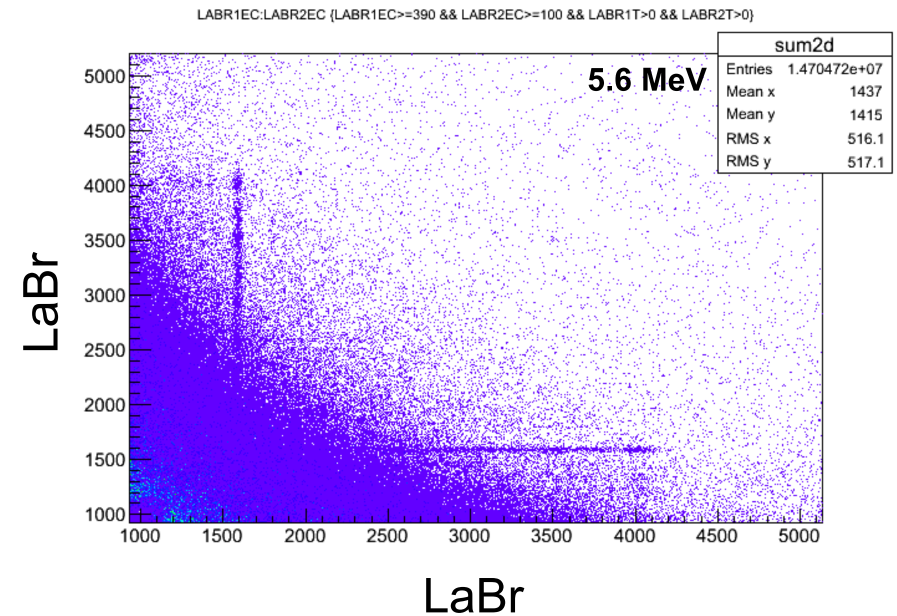
E(2^+_1) = 1596 keV

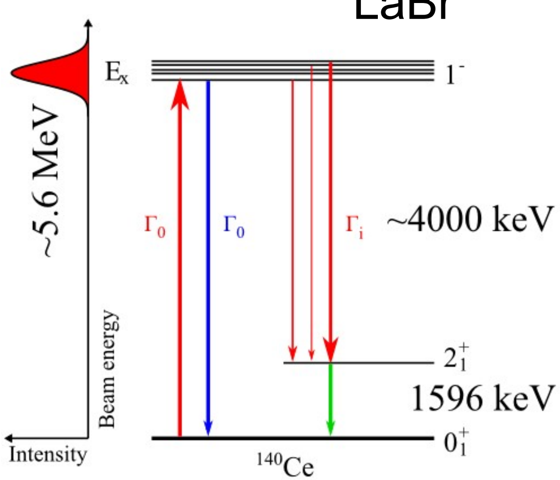


^{140}Ce (γ,γ')

Experimental data yields two matrices:





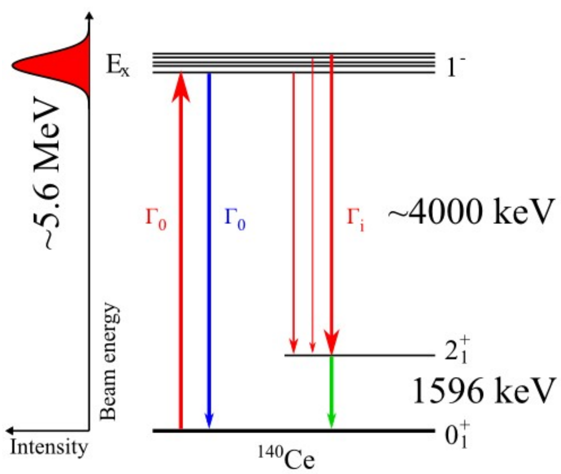


3 possible analyses:

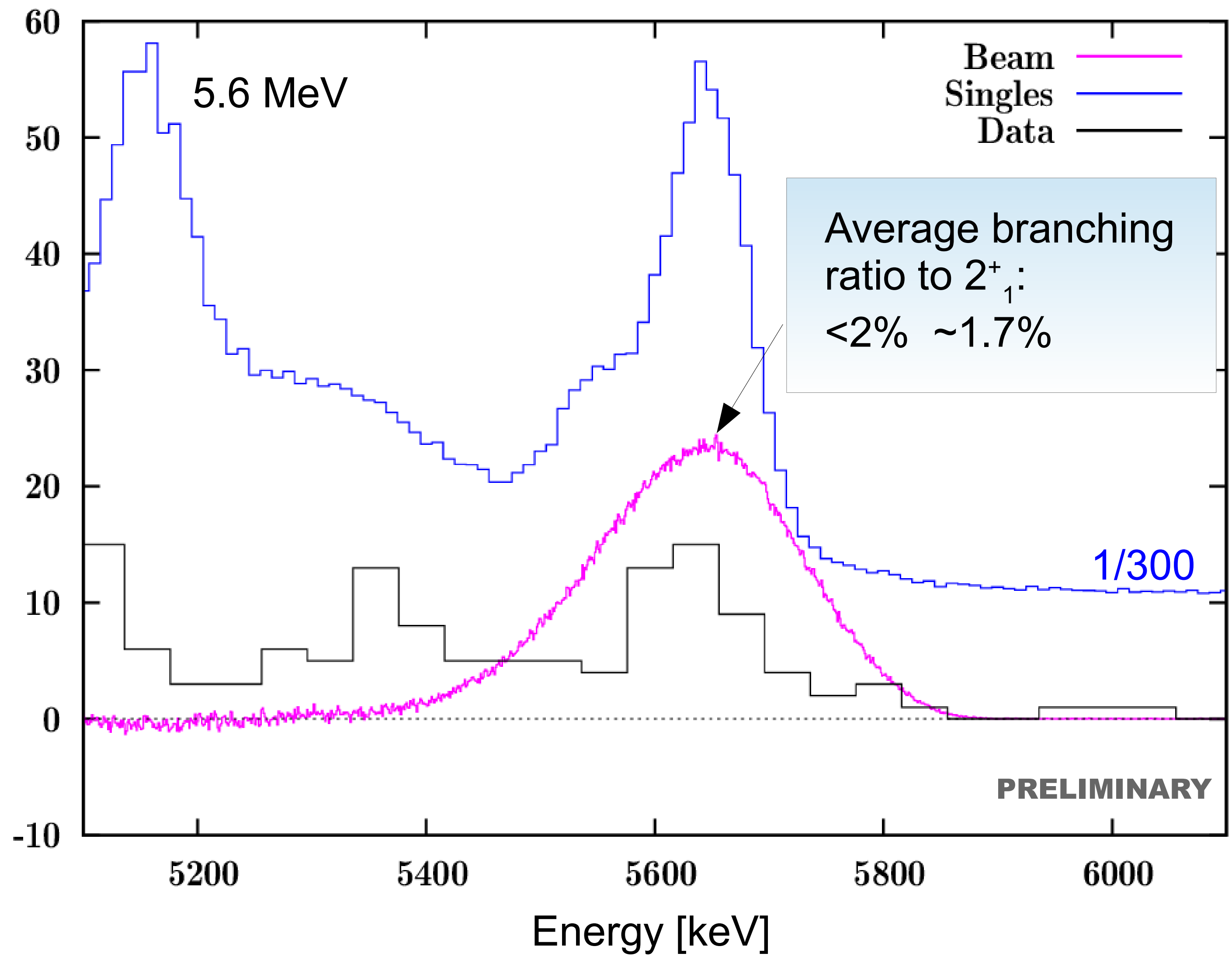
- Gate on $2^+_1 \rightarrow 0^+$ in LaBr:
  1) HPGe spectra (high resolution)
  2) LaBr spectra (better efficiency)
- Gate on $2^+_1 \rightarrow 0^+$ in HPGe:
  3) LaBr spectra (best signal to background)

^{140}Ce (γ,γ')

Gate on HPGe → LaBr spectra

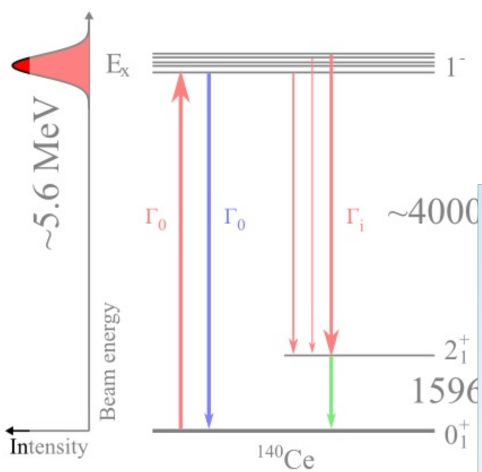


E(2$^{+}_{1}$) = 1596 keV

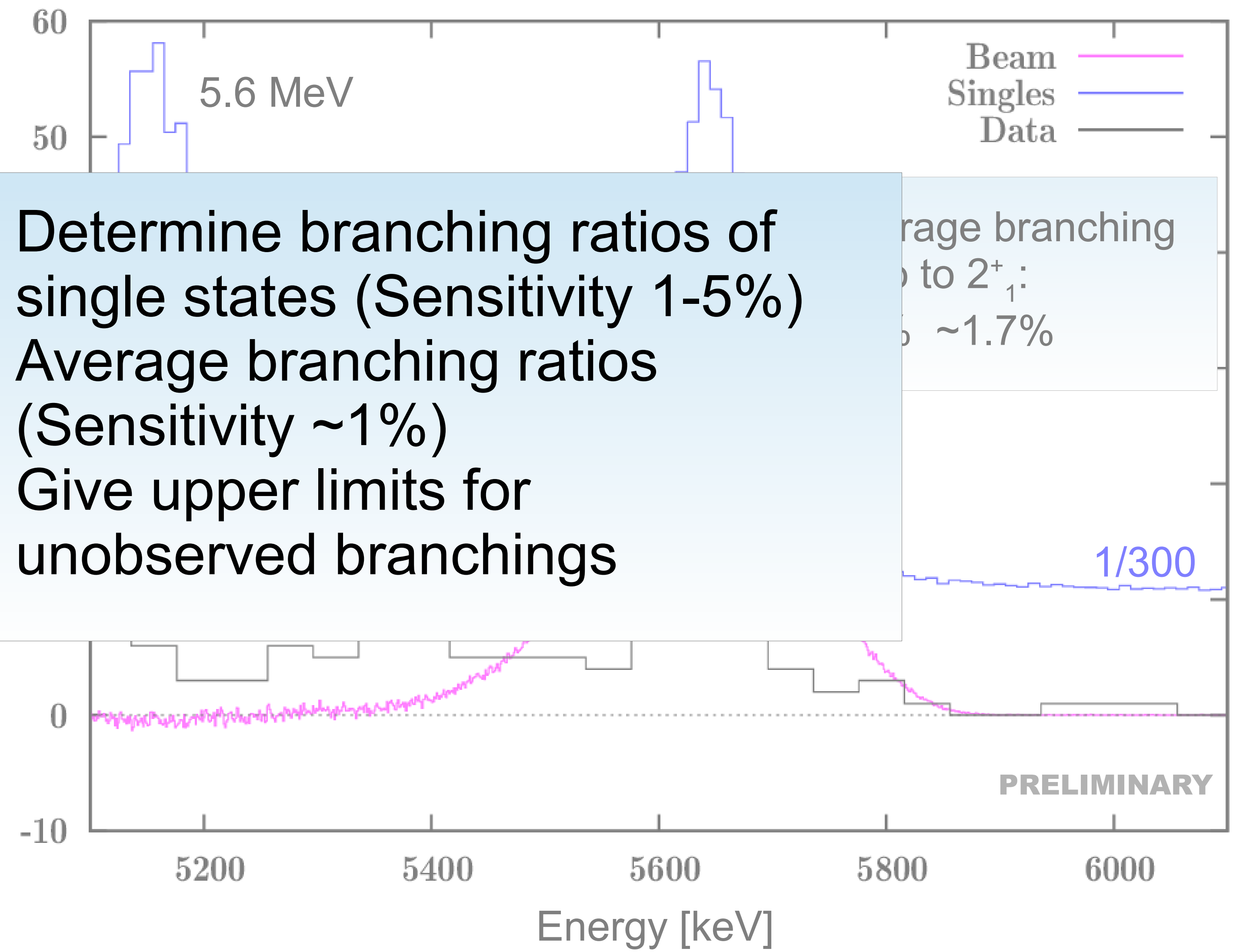


^{140}Ce (γ,γ')

Gate on HPGe → LaBr spectra



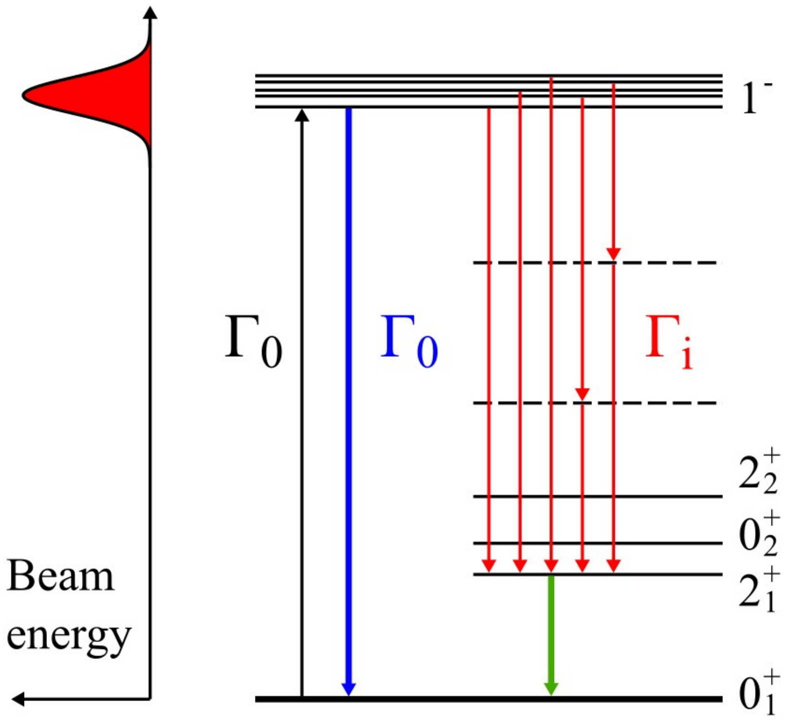
E(2^+_1) = 1596 keV



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

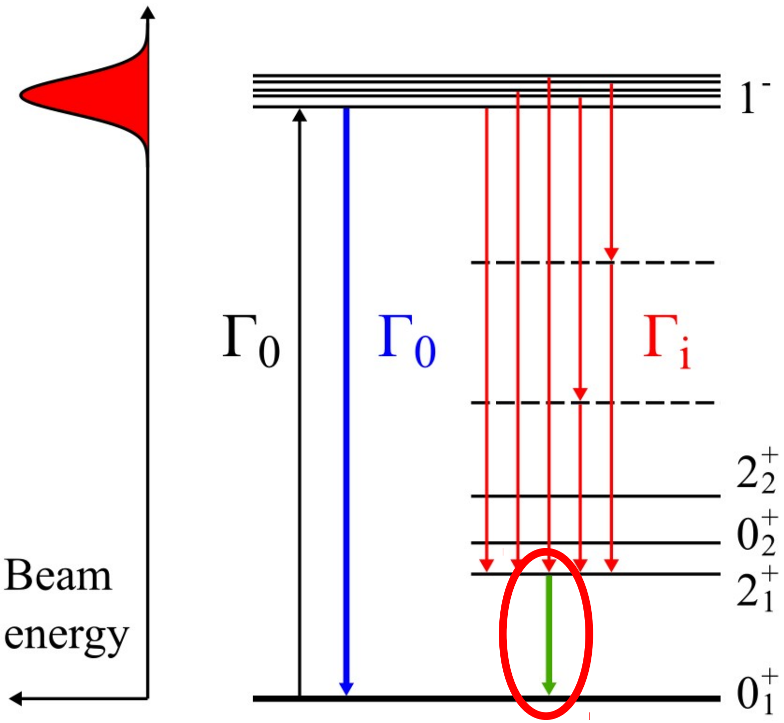
^{140}Ce (γ,γ')

Determination of branching via low-lying states



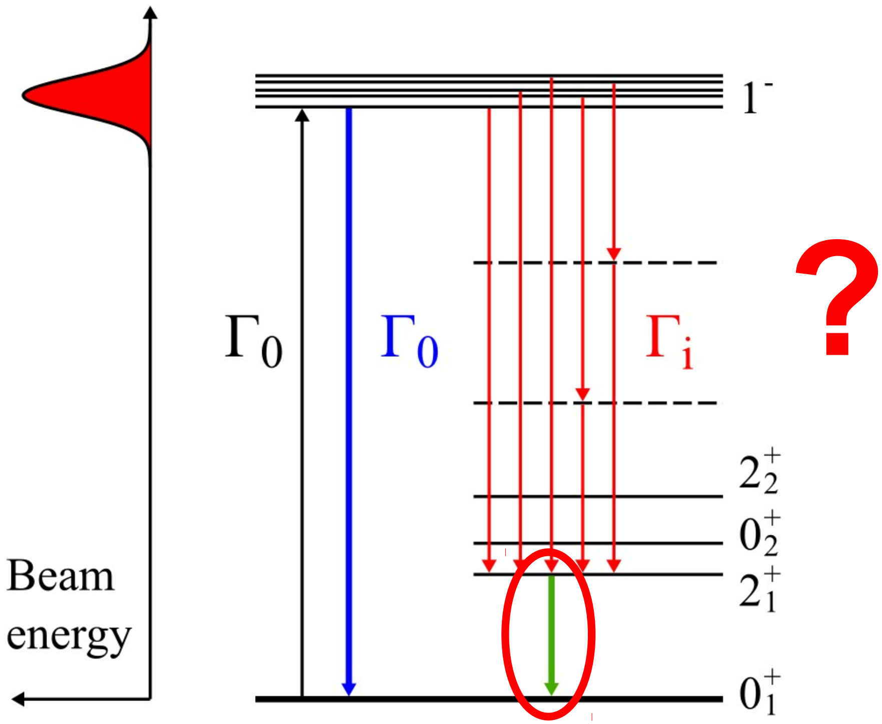
^{140}Ce (γ,γ')

Determination of branching via low-lying states



^{140}Ce (γ,γ')

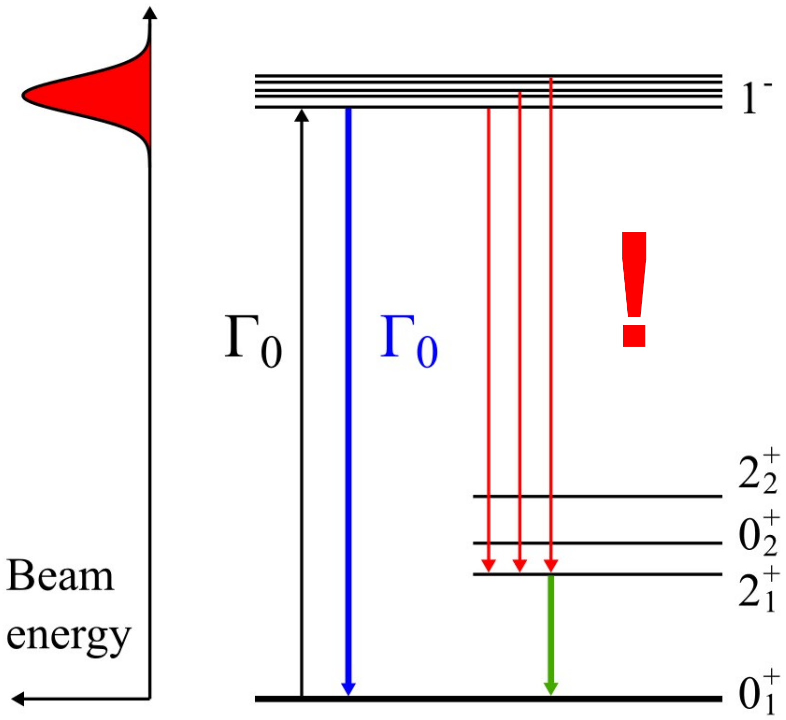
Determination of branching via low-lying states



Problem: Population of state not determined

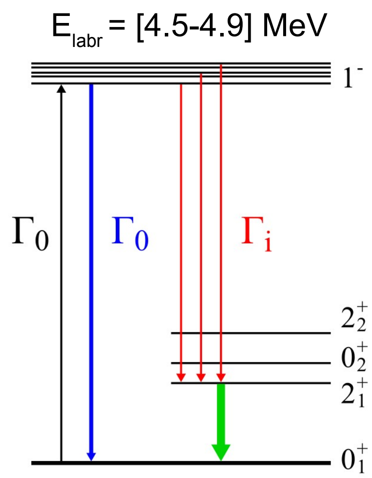
^{140}Ce (γ,γ')

Determination of branching via low-lying states

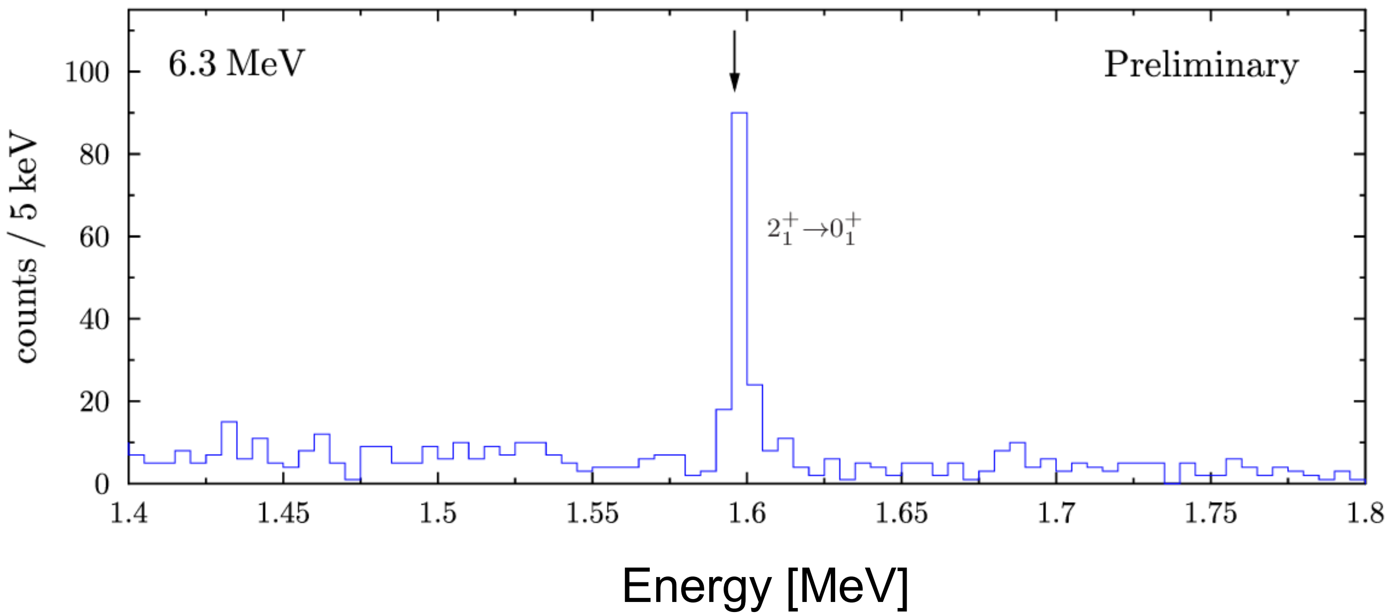


Solution: Use coincidence condition on high energy transitions
→ Restrict to narrow energy band

^{140}Ce (γ,γ')

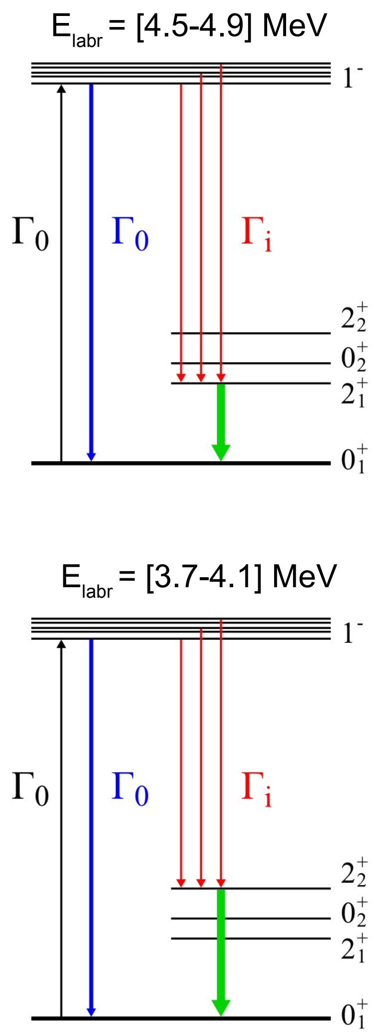


E_labr = [4.5-4.9] MeV
1-
Γ0
Γ0
Γi
2+2
0+2
2+1
0+1

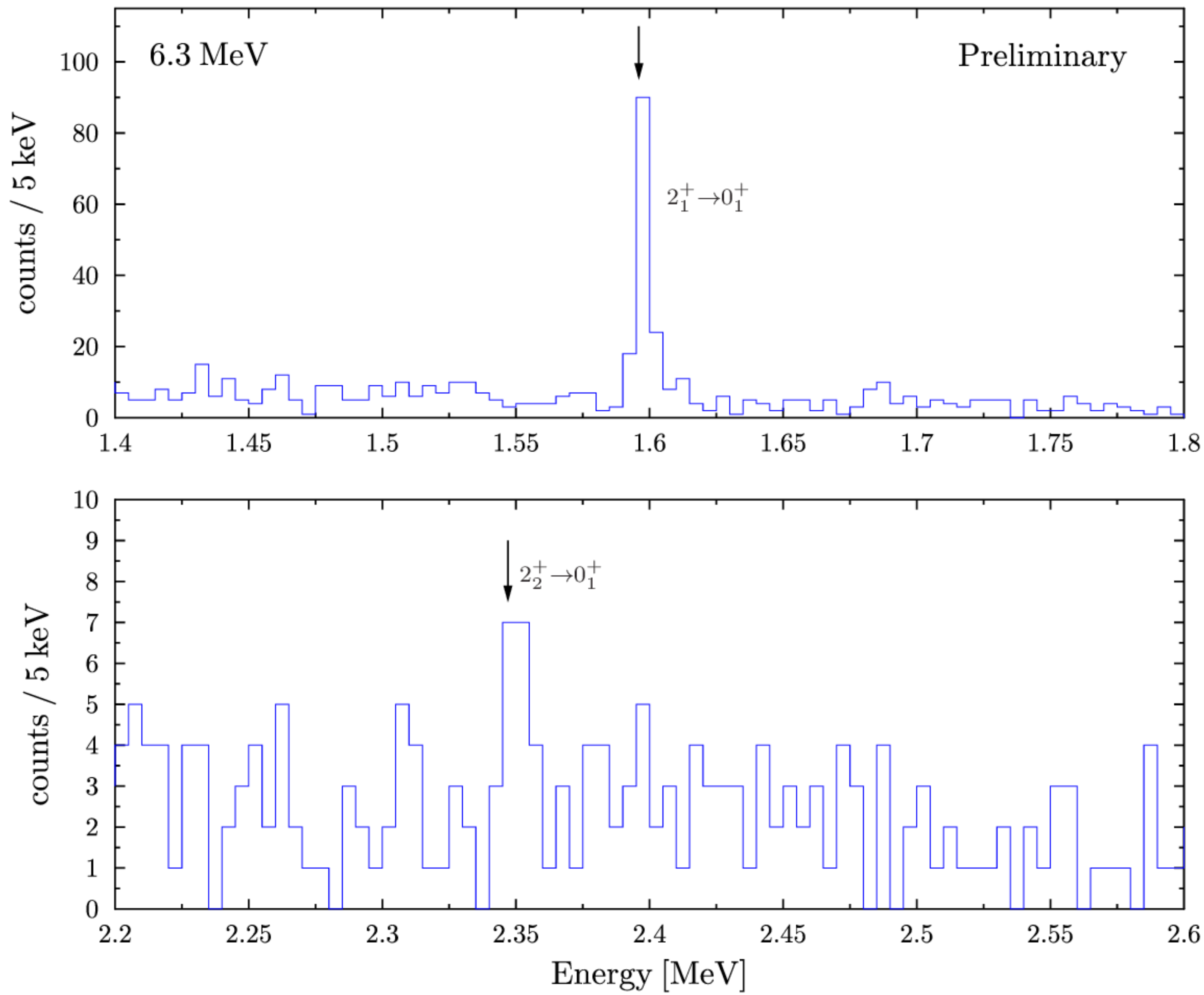


6.3 MeV
Preliminary
counts / 5 keV
2+1→0+1
Energy [MeV]

^{140}Ce (γ,γ')

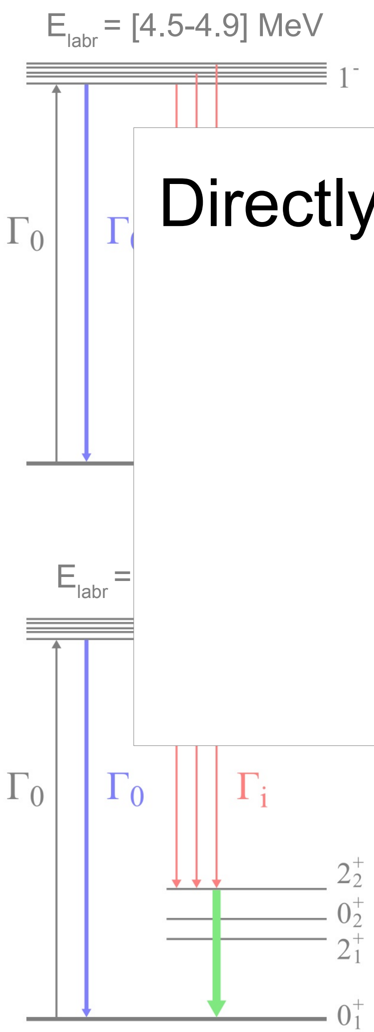


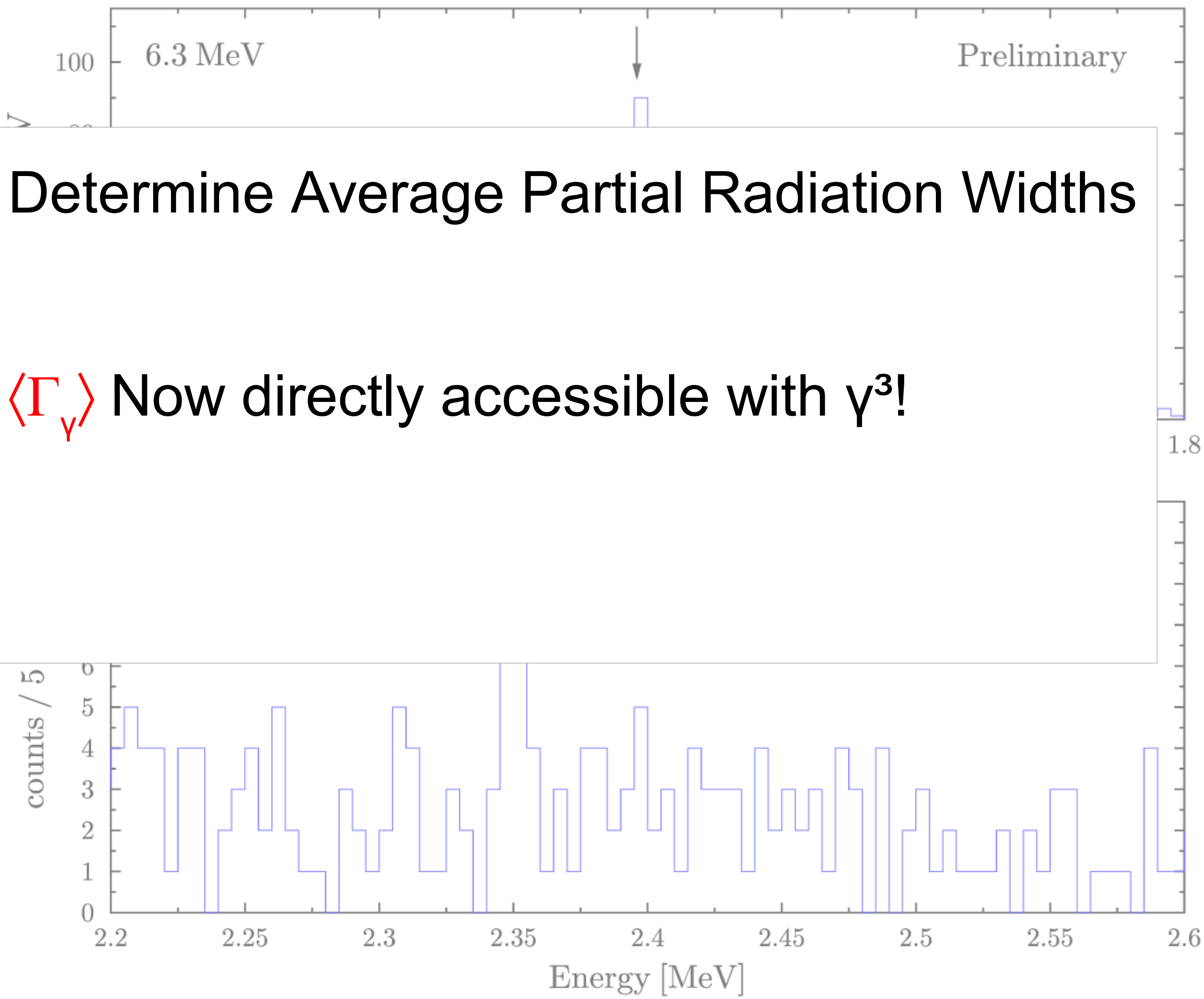
E_labr = [4.5-4.9] MeV
1⁻
Γ0
Γ0
Γi
2+2
0+2
2+1
0+1
E_labr = [3.7-4.1] MeV
1⁻
Γ0
Γ0
Γi
2+2
0+2
2+1
0+1



6.3 MeV
Preliminary
2+1→0+1
counts / 5 keV
100
80
60
40
20
0
1.4
1.45
1.5
1.55
1.6
1.65
1.7
1.75
1.8
2+2→0+1
counts / 5 keV
10
9
8
7
6
5
4
3
2
1
0
2.2
2.25
2.3
2.35
2.4
2.45
2.5
2.55
2.6
Energy [MeV]

^{140}Ce (γ,γ')

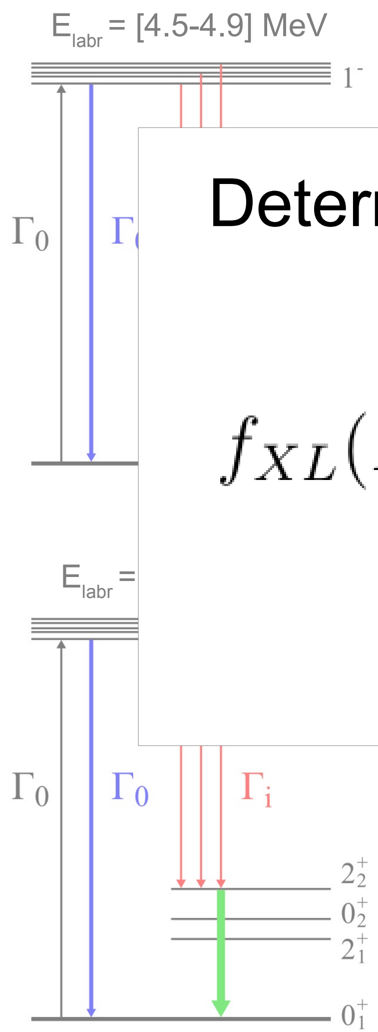


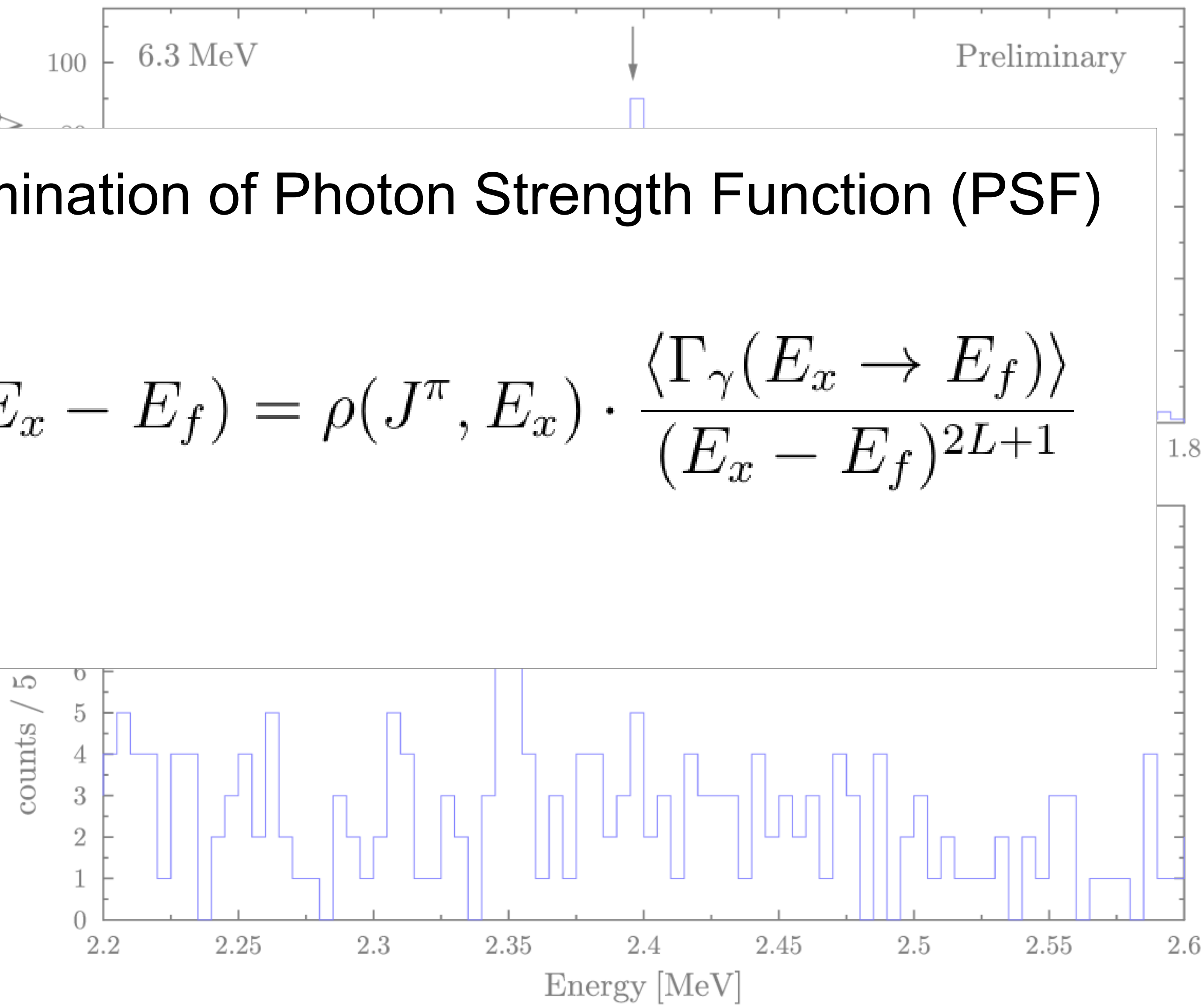


Directly Determine Average Partial Radiation Widths

$\langle\Gamma_\gamma\rangle$ Now directly accessible with γ³!

^{140}Ce (γ,γ')

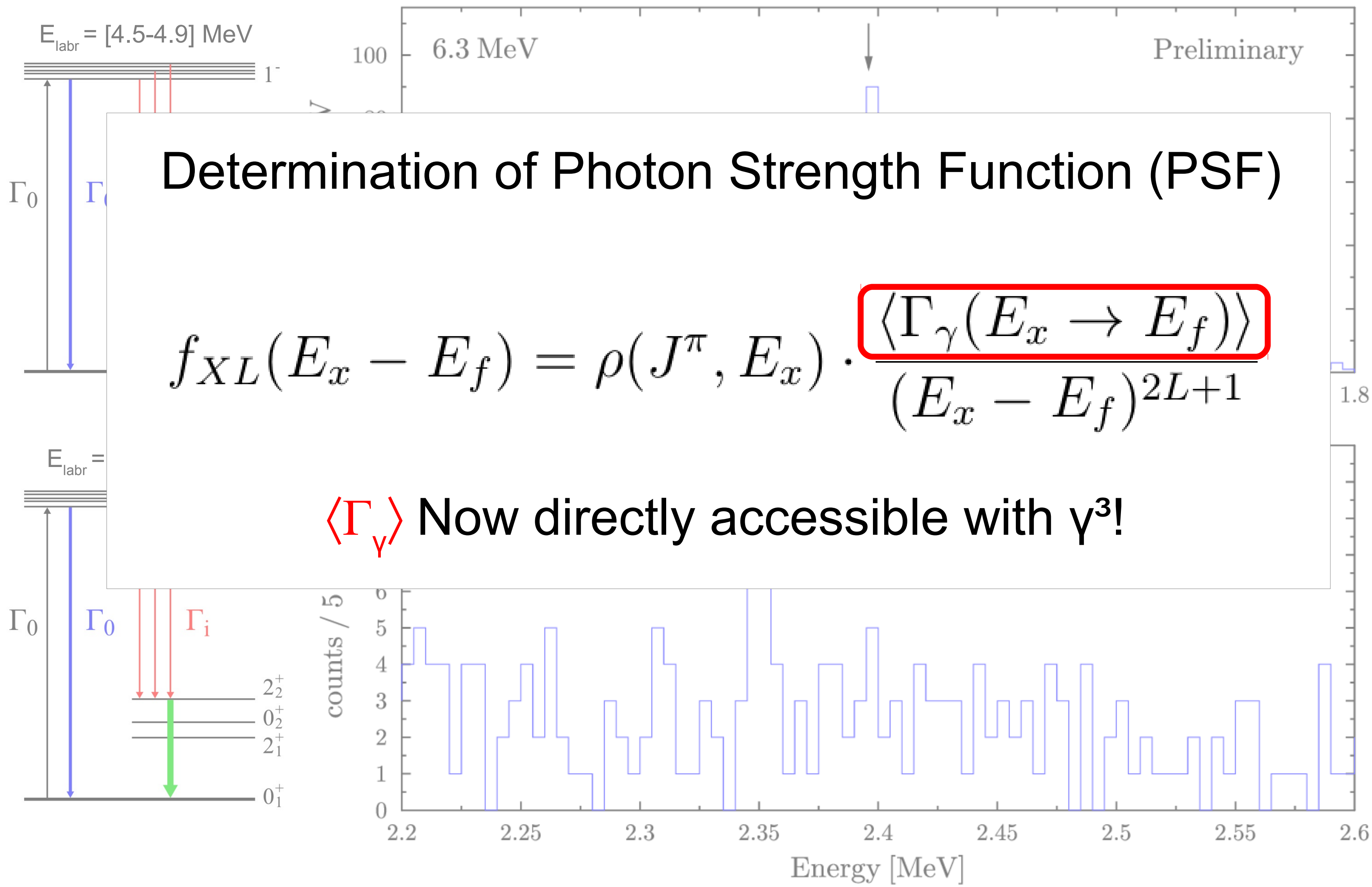




Determination of Photon Strength Function (PSF)

$$f_{XL}(E_x - E_f) = \rho(J^\pi, E_x) \cdot \frac{\langle \Gamma_\gamma(E_x \to E_f) \rangle}{(E_x - E_f)^{2L+1}}$$

^{140}Ce (γ,γ')



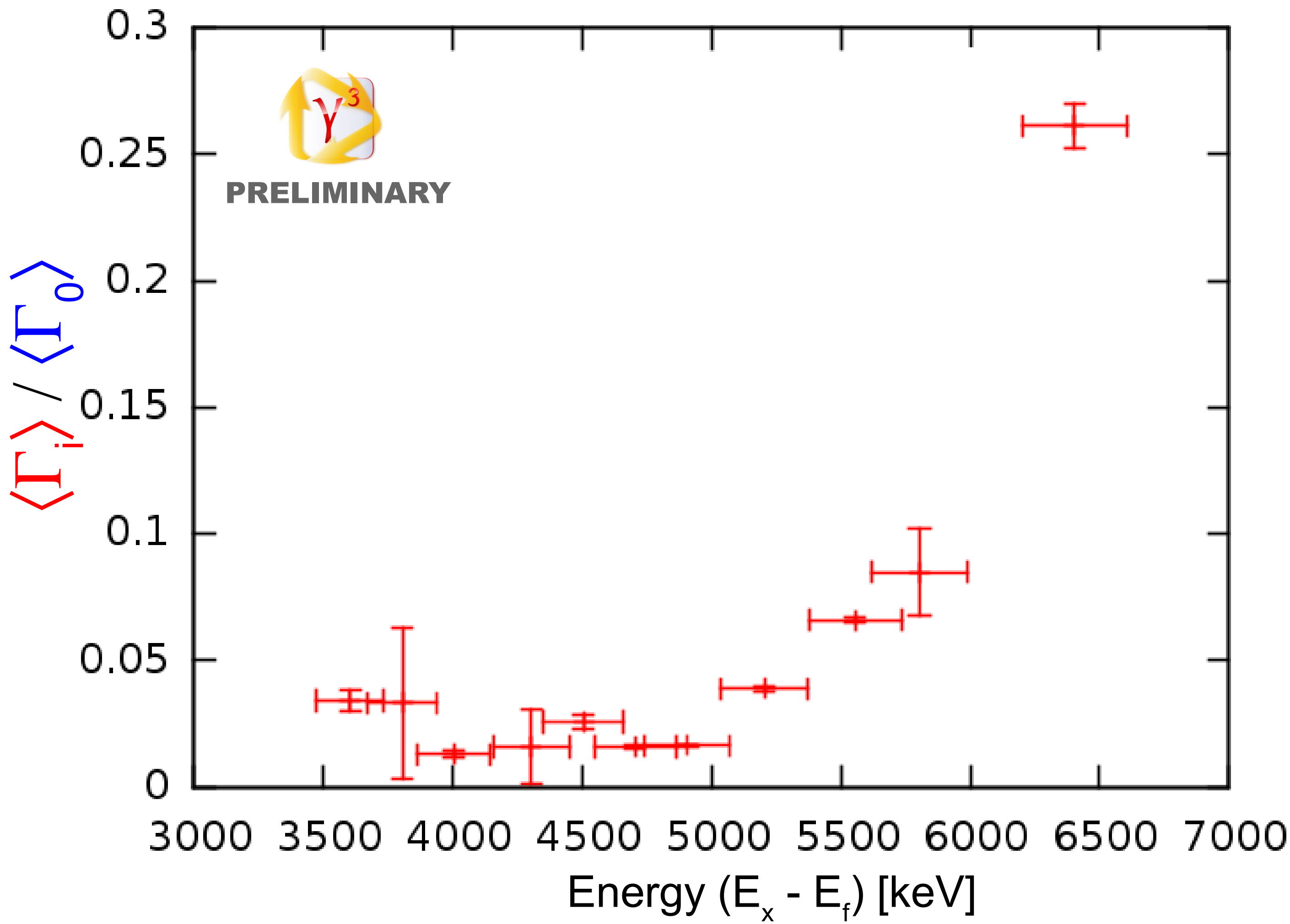
Determination of Photon Strength Function (PSF)

$$f_{XL}(E_x - E_f) = \rho(J^\pi, E_x) \cdot \frac{\boxed{\langle \Gamma_\gamma(E_x \rightarrow E_f) \rangle}}{(E_x - E_f)^{2L+1}}$$

$\langle \Gamma_\gamma \rangle$ Now directly accessible with γ³!

^{140}Ce (γ,γ')

PSF determination from decays to the first 2$^+$ state

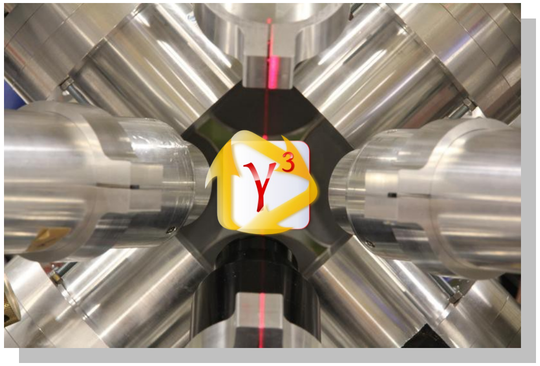


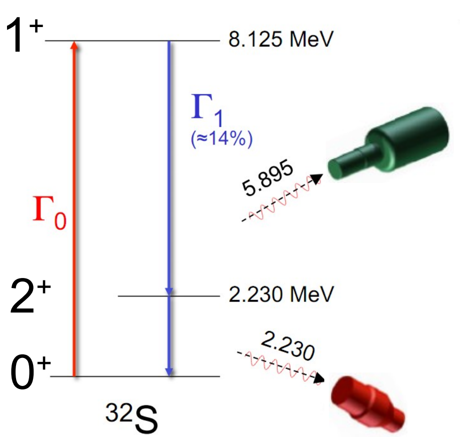
Outlook

- Analysis of ^{140}Ce data ongoing
- Next γ^3 beam time starting in August 2013
  - PDR in ^{206}Pb
  - Scissors Mode in ^{162,164}Dy
  - Photon strength function in ^{128}Te

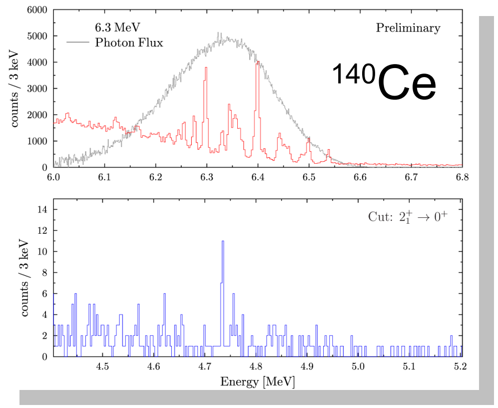
γ³ Collaboration

28.05.2013





Commissioning



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- **TU Darmstadt**
  - T.Aumann, J.Beller, M.Duchêne, M.Knörzer, N.Pietralla, M.Scheck, H.Scheit
- **Universität zu Köln (Cologne)**
  - 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