Study of EM Properties Along the Carbon Isotopic Chain & O-21

A Status Report From A03

M. Mathy[1], Sebastian Heil[1], Ina Syndikus[1] and M. Petri[2,1]

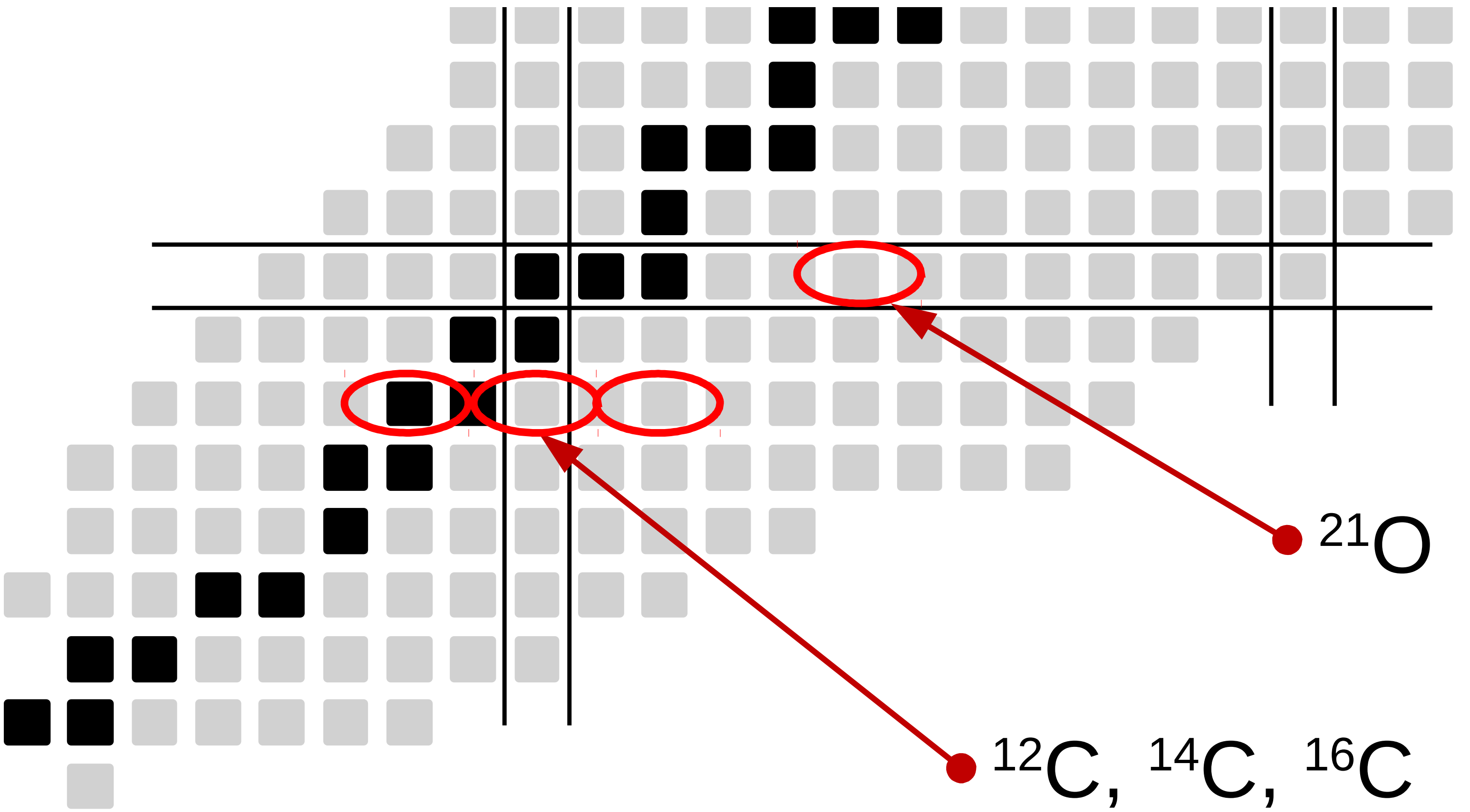
[1]Institut für Kernphysik, TU Darmstadt, Germany; [2]Department of Physics, University of York, United Kingdom

This work was supported by the DFG under contract No. SFB 1245.

Outline

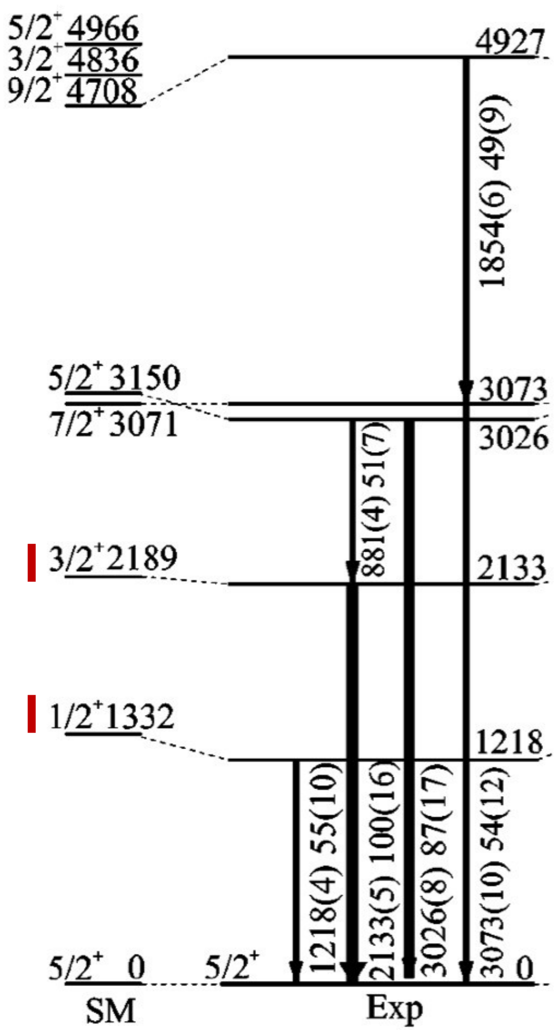
TECHNISCHE UNIVERSITÄT DARMSTADT

Study of EM properties for light & medium mass nuclei:



Oxygen-21

Oxygen-21: Motivation



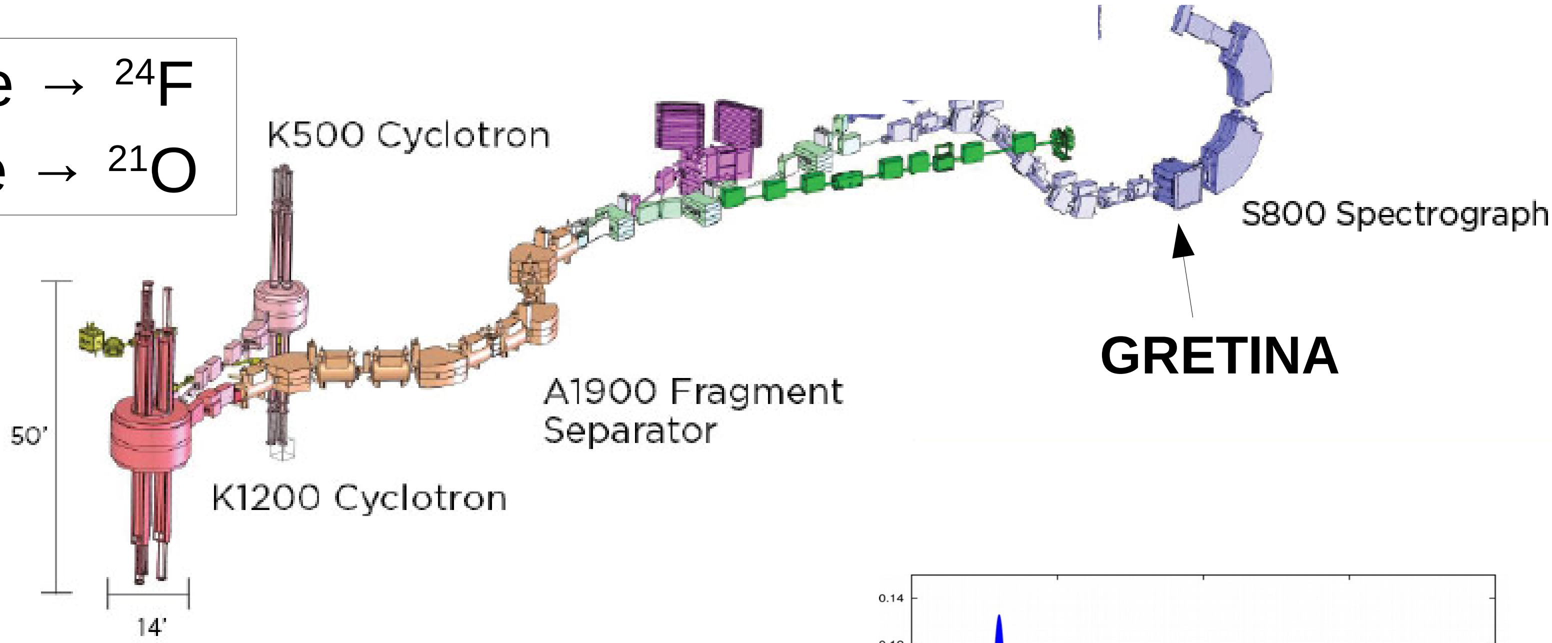
- Theoretical predictions differ significantly:

Chiral NN+3N	E_γ (keV)	BR (%)	τ (ps)
1/2 --> 5/2	1218	-	**100**
3/2 --> 5/2	2133	**90**	2.8
3/2 --> 1/2	915	**10**	-
USDB	**E_γ (keV)**	**BR (%)**	**τ (ps)**
1/2 --> 5/2	1218	-	**154**
3/2 --> 5/2	2133	**78**	2.2
3/2 --> 1/2	915	**22**	-

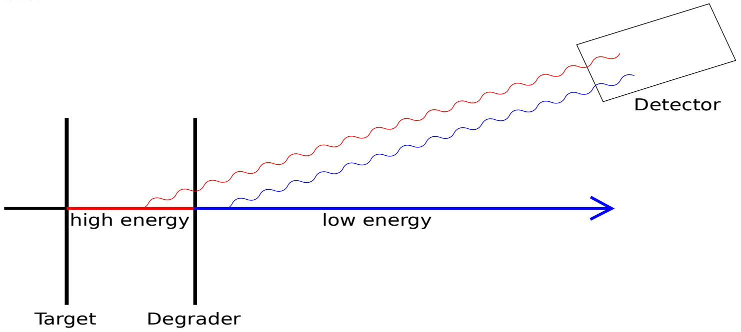
Oxygen-21: Experimental Setup

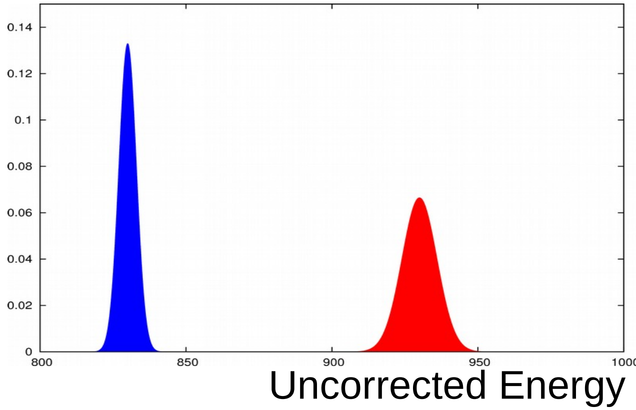
Measure Lifetime of 1/2$^+$ in ^{21}O at MSU:

^{48}Ca + ^{9}Be → ^{24}F
^{24}F + ^{9}Be → ^{21}O

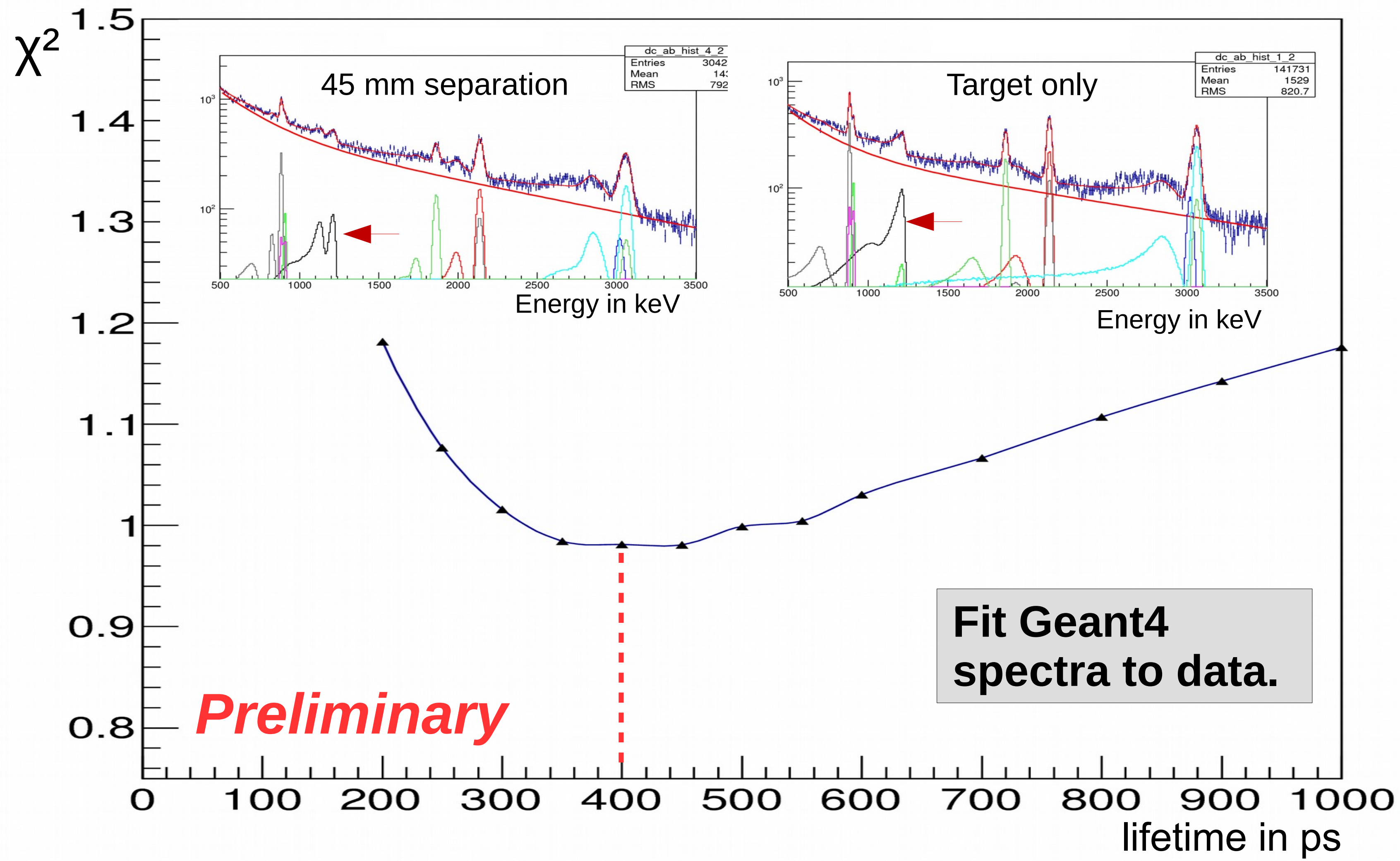


Doppler Shift Recoil Method:





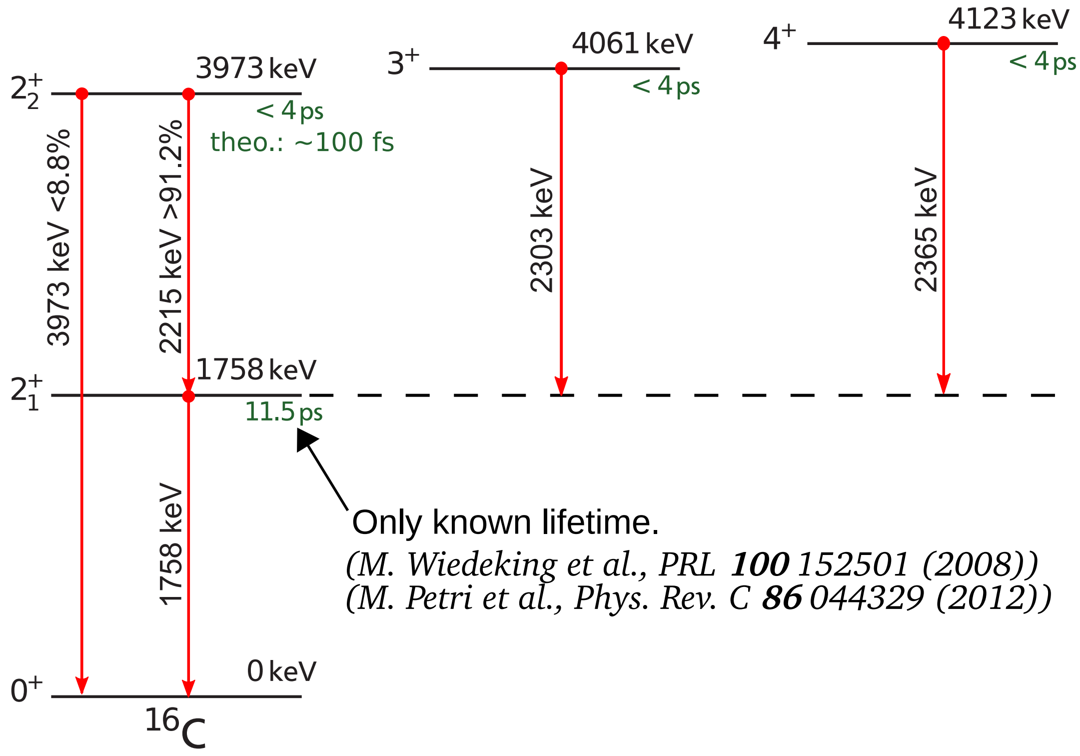
Oxygen-21: First Results for 1/2$^+$



Carbon-16

Carbon-16: Motivation & Recap

EM observables in C-16 are strongly sensitive to the details of the nuclear Hamiltonian:

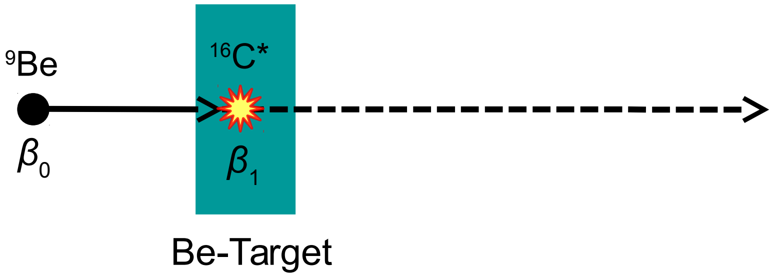


Used GAMMASPHERE and μ-Ball at Argonne National Lab to measure:

- The lifetimes of the 2_2^+, 3^+ and 4^+ states.

Carbon-16: Motivation & Recap

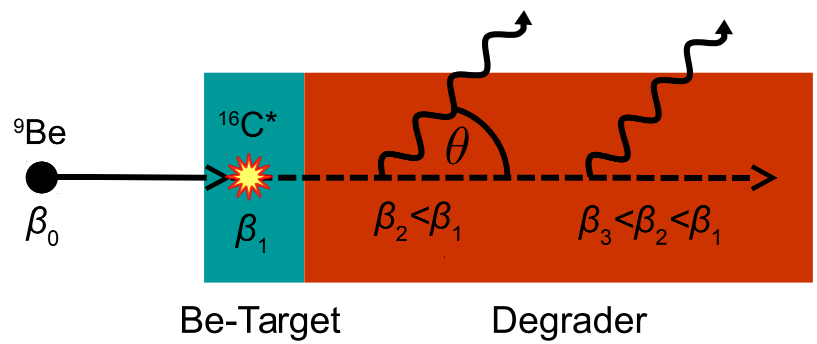
- Use fusion-evaporation to produced ^{16}**C**: **^{9}Be(^{9}Be,2p)^{16}C***
- Gate on 2**p** with particle detector ***μ*-Ball** and detect the emitted γ-rays in coincidence with **GAMMASPHERE**.
- Expected lifetimes with $\tau_{cm} < 4$ ps are rather short.



Carbon-16: Motivation & Recap

- Use fusion-evaporation to produced ^{16}**C**: **^{9}Be(^{9}Be,2p)^{16}C***
- Gate on 2**p** with particle detector ***μ*-Ball** and detect the emitted γ-rays in coincidence with **GAMMASPHERE**.
- Expected lifetimes with $\tau_{cm} < 4$ ps are rather short.
- Measure τ in-fight with the Doppler-shift-attenuation method:

$$E_{\text{Lab}} = E_{\text{CM}} \frac{\sqrt{1-\beta^2}}{1-\beta\cos(\theta)};\ \beta = v/c$$



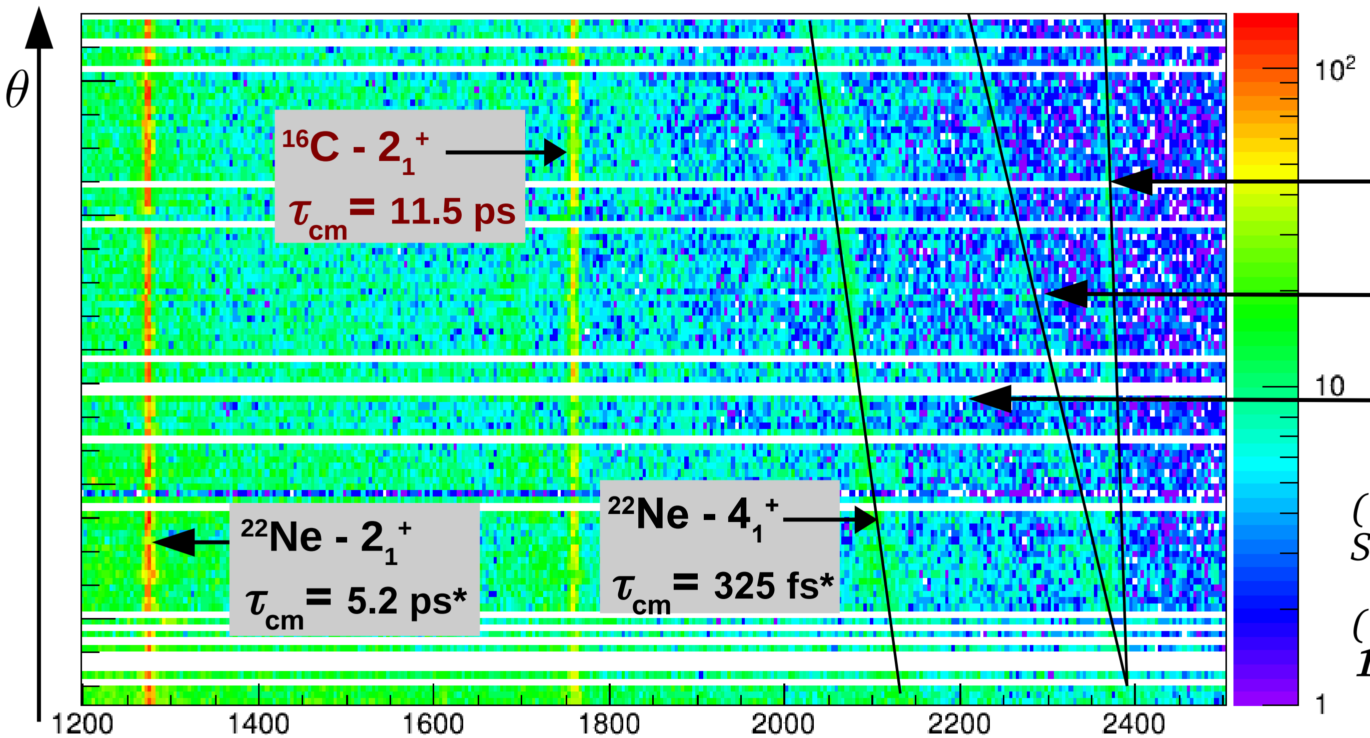
- Shorter τ → Larger mean decay β → Stronger energy shift due to Doppler effect.

Energy shift for different radiation angle $\theta \rightarrow \tau$

Carbon-16: Latest Progress

TECHNISCHE UNIVERSITÄT DARMSTADT

Detector Angle θ vs. Uncorrected Energy with 2p Cut:



(*M.S. Basunia, Nucl. Data Sheets ***27***, 69 (2015))

(**M. Wiedeking et al., PRL ***100*** 152501 (2008))

- **Origin of ^{22}Ne:** Target was oxidized: **^{9}Be + ^{16}O → ^{22}Ne + 2pn**
- The 2_2^+ state can not be seen for this low intensities (~50% of the 4^+ or 3^+ state**).
- Slope is sensitive to lifetime → Compare with Geant4 simulations.

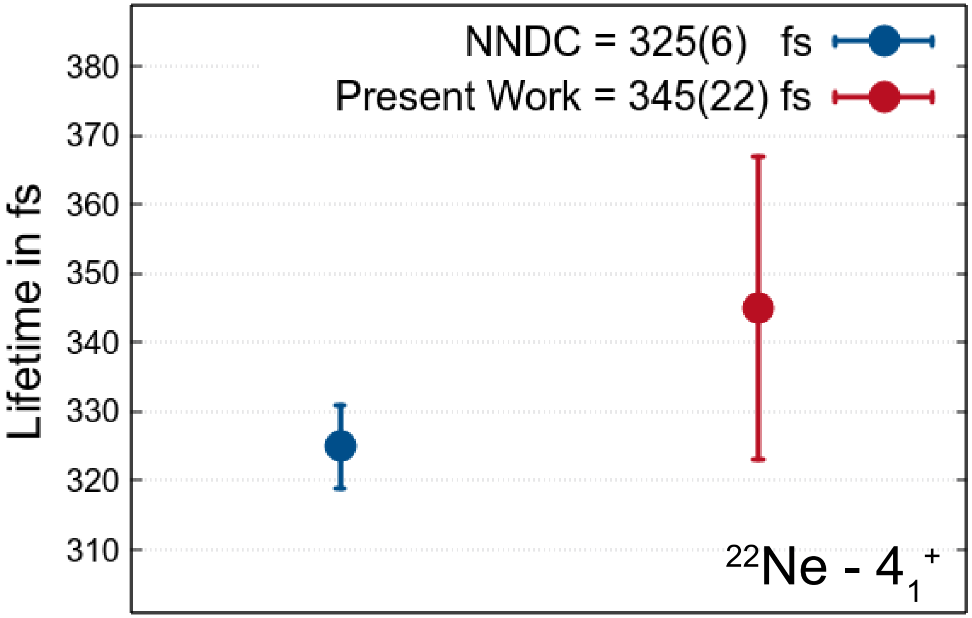
Carbon-16: Latest Progress

TECHNISCHE UNIVERSITÄT DARMSTADT

Test Realistic Geant4 Simulation with ^{22}Ne - 4_1^+:

In the Geant4 Simulation:

- Generate excited ^{22}Ne isotopes in a thin oxidation layer.
- Do this for many lifetimes and compare the slopes with experiment.
- Latest Result:



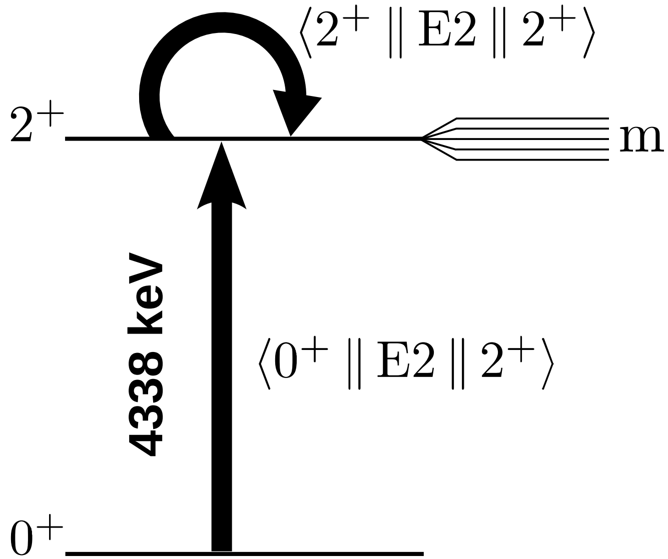
Preliminary

(M.S. Basunia, Nucl. Data Sheets ***27,*** *69 (2015))*

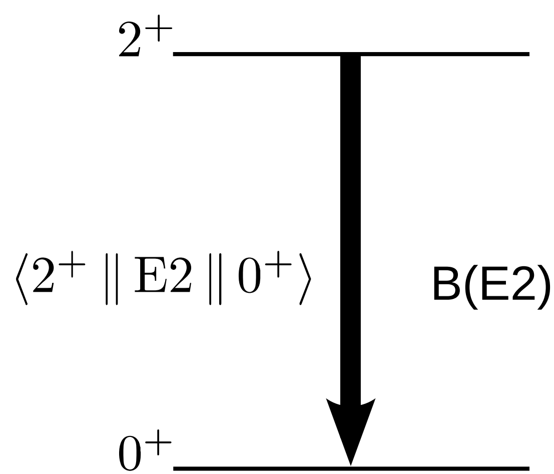
Carbon-12

Carbon-12: Motivation

- Carbon-12 is a prime nucleus for many ab initio calculations.
- Exp. $Q(2^+)$ uncertainties are larger than theory's.



Coulomb Excitation @ JYFL



Photon Scattering @ SDALINAC

- Uniquely combine two experiments to reduce the experimental uncertainty. → High precision experiment for $Q(2^+)$.

Carbon-12: Latest Q(2⁺) Measurement

arXiv:1709.07501v1 [nucl-ex] 21 Sep 2017

Reorientation-effect measurement of the first 2^+ state in ^{12}C: confirmation of oblate deformation

Result: $Q_s(2^+) = (+0.053 \pm 0.044)\,\mathrm{eb}$ → **83%** uncertainty

Our result:

- Without new NRF measurement: **<29%** uncertainty in the Q(2+)
- With new NRF measurement: ~2% uncertainty for B(E2)

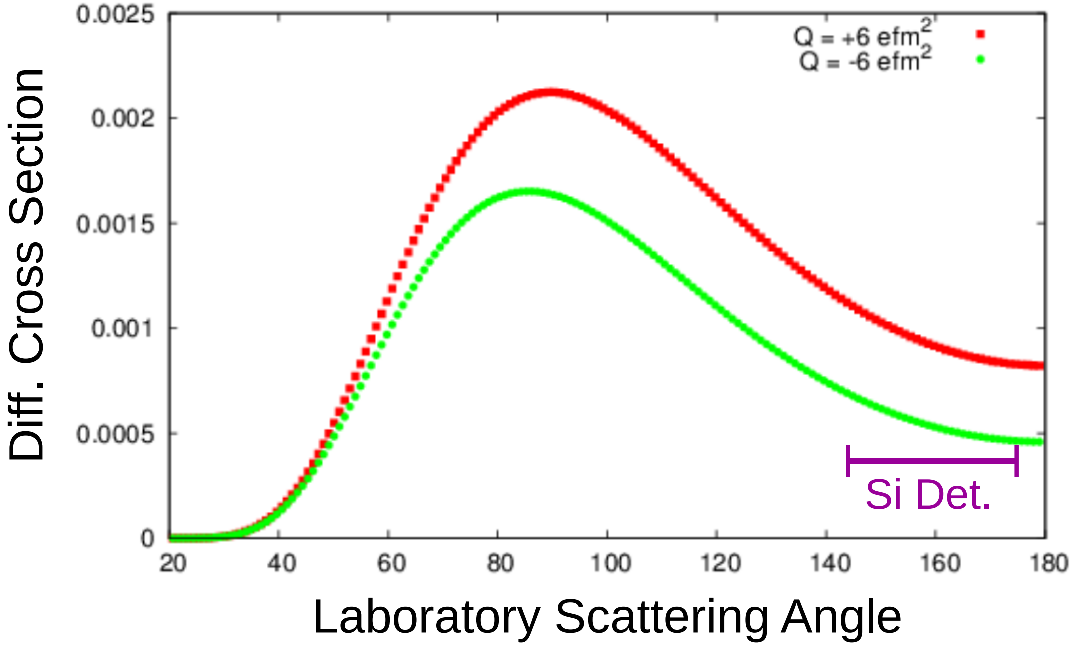
  <18% uncertainty in the Q(2+)

Carbon-12: The Experiment at JYFL

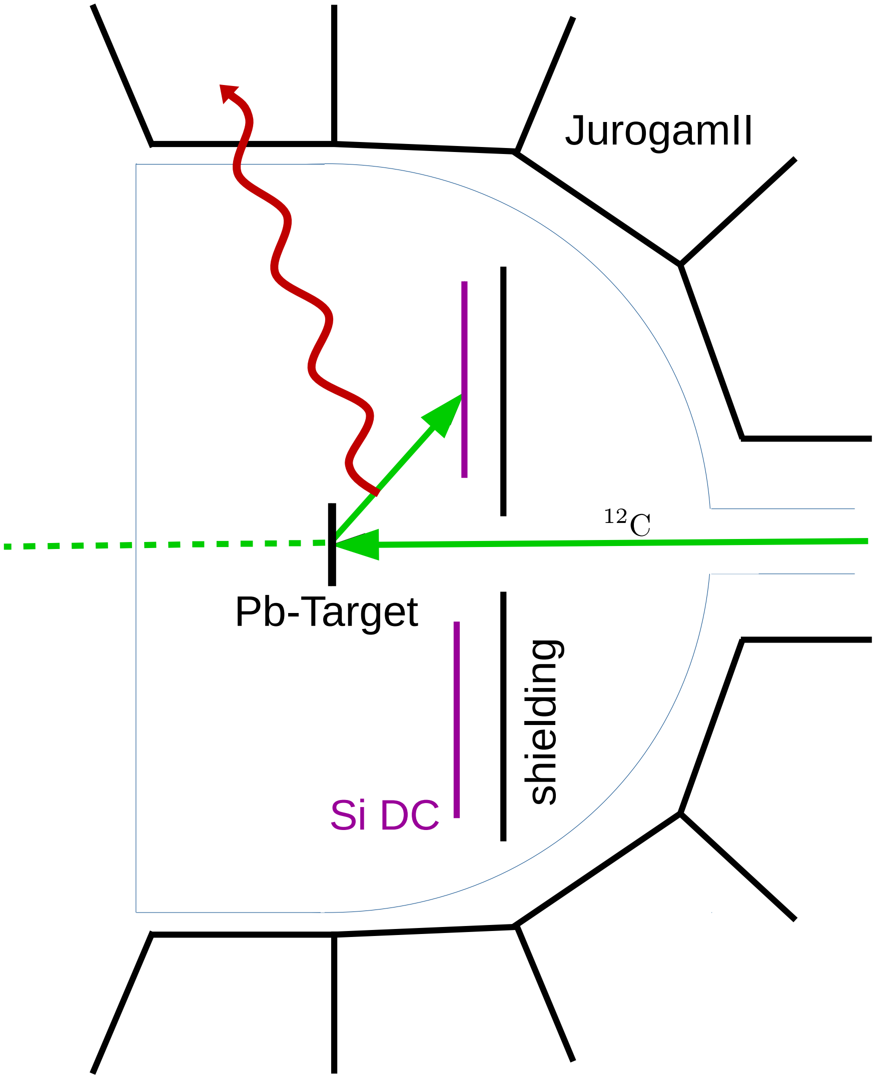
- Using Coulomb excitation to measure the transition strength in C-12 @ 4338 keV.

- Measure scattered C-12 at backward angles with position sensitive silicon detectors.

- Measure relative to Pb-208 3_1^- state @ 2614 keV! Precision of B(E3) ~1.5%!



Carbon-12: The Experiment at JYFL



- Incoming beam:
  - $^{12}C^{4+}$
  - E = 47.5 MeV
- Target:
  - 300 µm/cm^2 ^{208}Pb
- Si CD: measure backscattered ^{12}C
- HPGe array JurogamII to measure gamma rays.

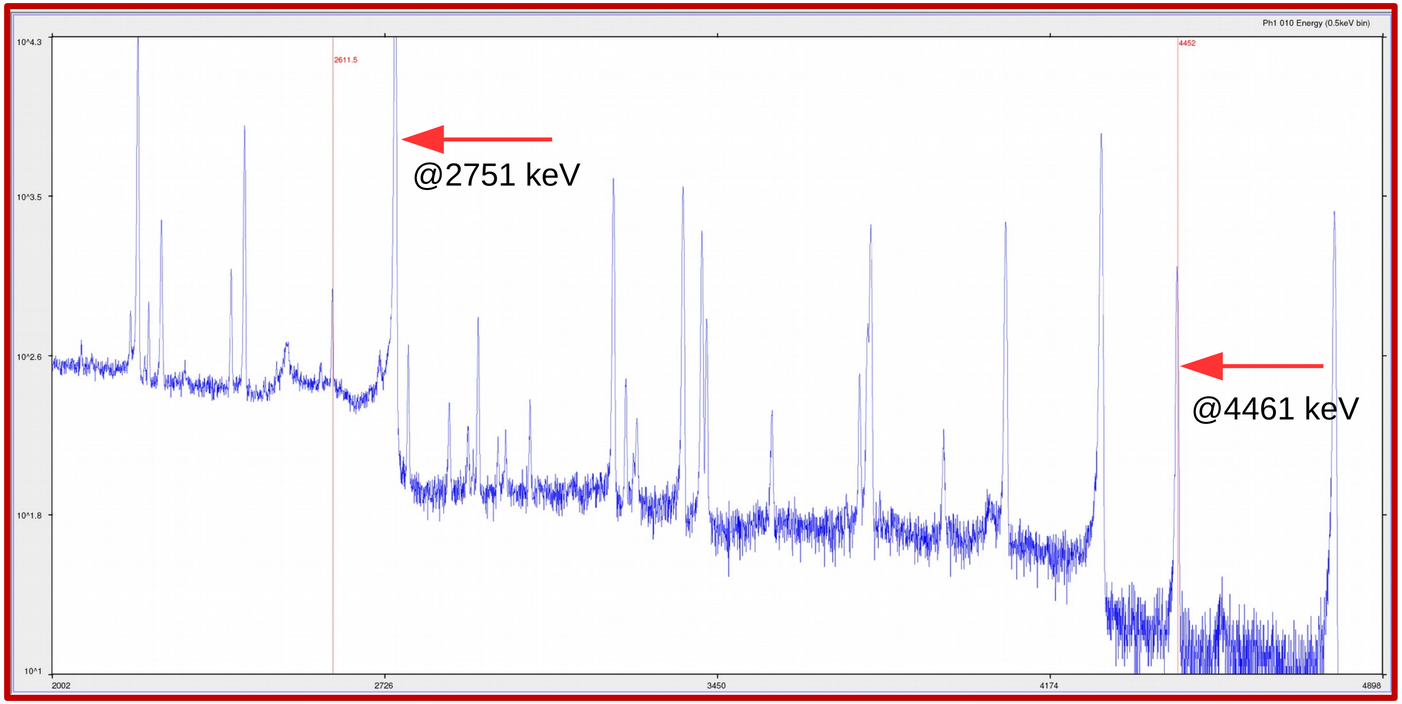
Carbon-12: The Experiment at JYFL

Important: Efficiency Calibration of JurogamII

- Low energy range (E<2 MeV) with “standard” sources:

Co-60, Eu-152, Ba-133

- **Special:** High energy range (E=0.8 to 5 MeV) using $^{nat}\mathrm{Zn(p,xn)}^{66}\mathrm{Ga}$

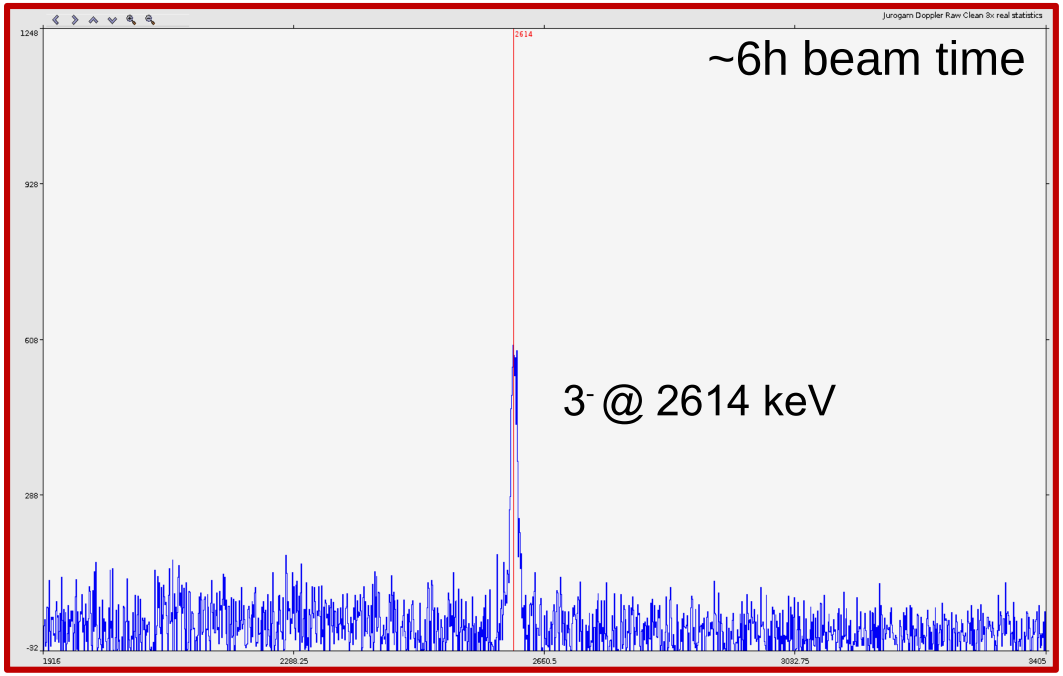


- 18 different gamma energies with precisely known intensity.

(Baglin et.al., Nucl. Instrum. Methods A, 481, 2002)

Carbon-12: The Experiment at JYFL

- Statistic for Pb-208 is ~66 times larger than for C-12.
- Doppler corrected gamma spectrum for **Pb-208** with C-12 in Si detector in coincidence:



The statistics we aimed for was reached!

Carbon-14

Carbon-14: Motivation & Recap

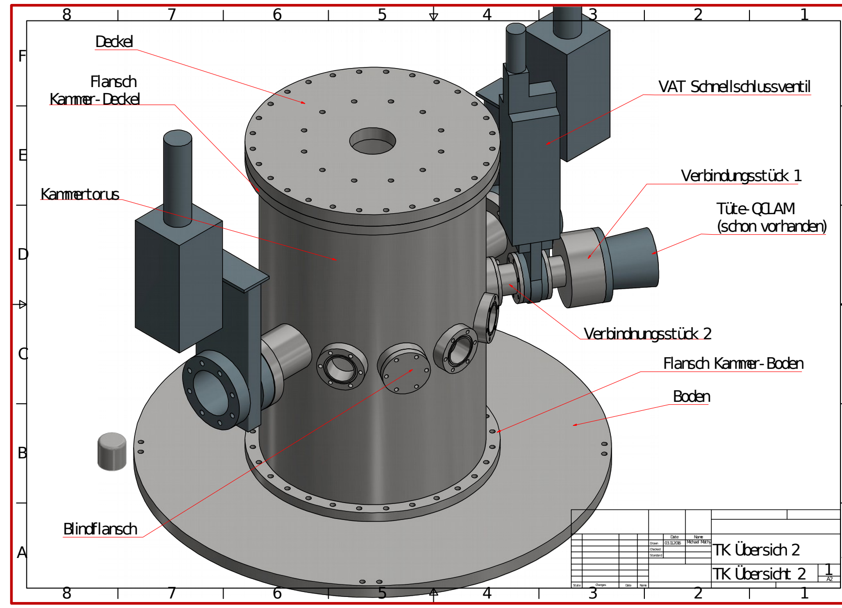
Perform (e,e’) on ^{14}C to extract form factors and transition strengths to low-lying excited states at the S-DALINAC:

- Also many excited states are not described well by theory.
- Challenging to theory due to cluster states.

- ~77mg/cm² radioactive ^{14}C target enabling (e,e’) for the first time in 4 decades.
- Measure the strengths for many states with improved precision or for the first time.

Carbon-14: Motivation & Recap

- Need a fast valve system for sudden vacuum failure.
- Fast piezo pressure sensors at top of the QCLAM.
- Designed a new Target chamber for QCLAM, which allows to place additional fast valves.



Carbon-14: Latest Progress

TECHNISCHE UNIVERSITÄT DARMSTADT

- Ordered and received most of the needed materials/parts: s*teel parts, vacuum parts, pressure sensors, fast closing valves*.

- Pressure sensors and special vacuum flange designed and tested successfully.

- In cooperation with *G. Steinhilber* & *M. Hilcker*:

  Worked on the vacuum system of QCLAM in general:
  Installed Zeoltih-filter system, tested (Turbo-)pumps, pressure sensors, connections…

Thank you for your attention!

Also special thanks to the *Spektrometer-Gruppe*

Appendix: Carbon-16

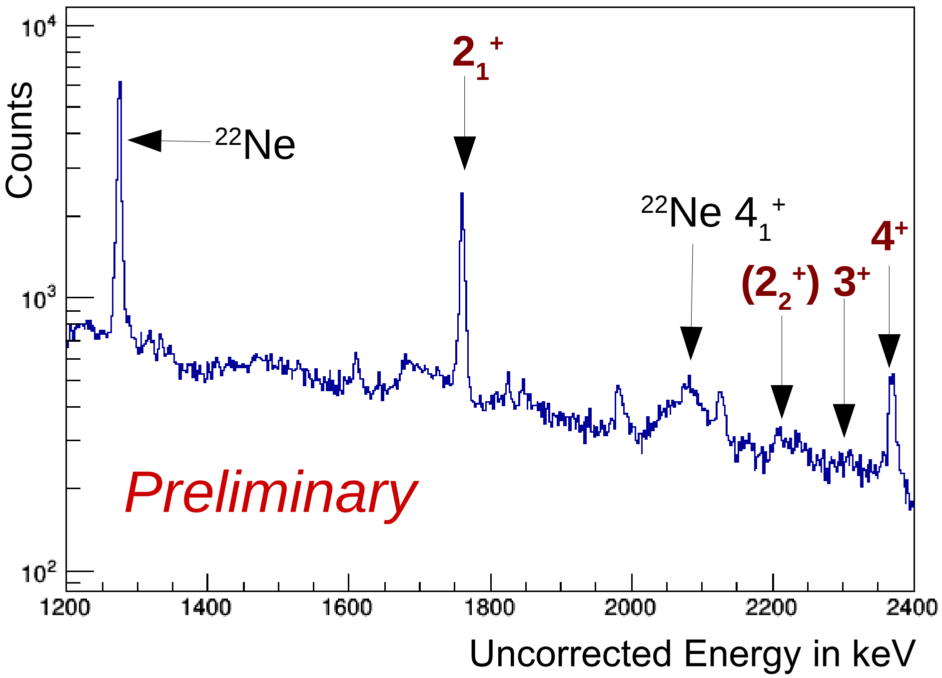
- Re-calibrated all GS detectors using 15 different energies from 245 keV to 6129 keV Sources: Y-88 / O-16 / Eu152 / Co56
  - → Result:
    - ➢ 23 detectors were not active during the experiment.
    - ➢ 3 detectors have a strange response.
    - ➢ 84 detectors can be used → Access to 16 rings.

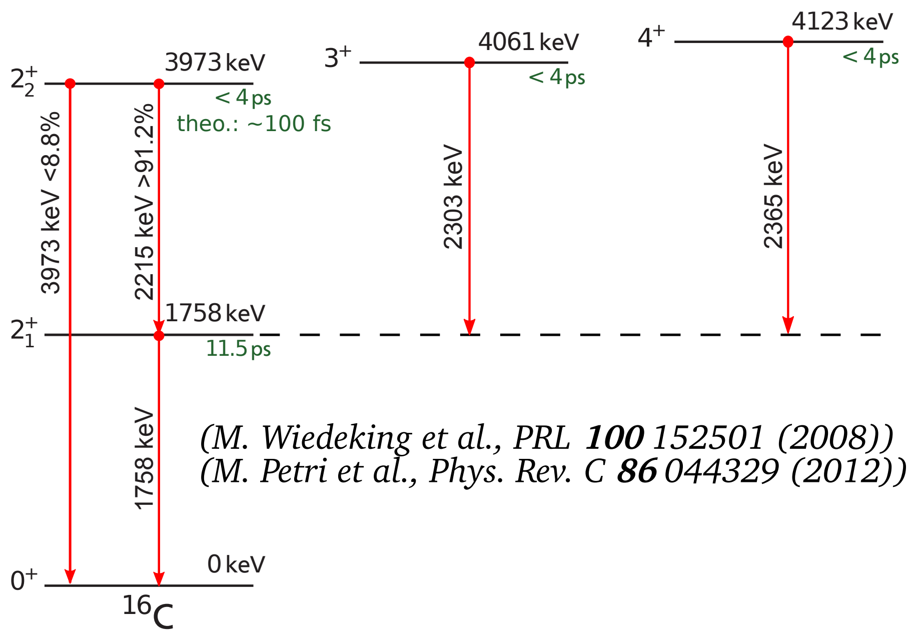
- For the first analysis (shown last year) the reached statistics were not satisfying:
  - → Redone ***μ*-Ball** 2D proton cuts (for every run file!) and coincidence window.
  - → Result: 30% more counts in C-16 2_1^+ state than before!

- Unfortunately the statistics is much lower than we aimed for! Reasons:
  - → Reached beam intensity is 28% of aim intensity.
  - → 2p efficiency of ***μ*-Ball** 36% of supposed efficiency
    - ➢ Only ~10% of the statistic we aimed for!

TECHNISCHE UNIVERSITÄT DARMSTADT

Total Uncorrected γ - Spectrum with 2p Cuts:

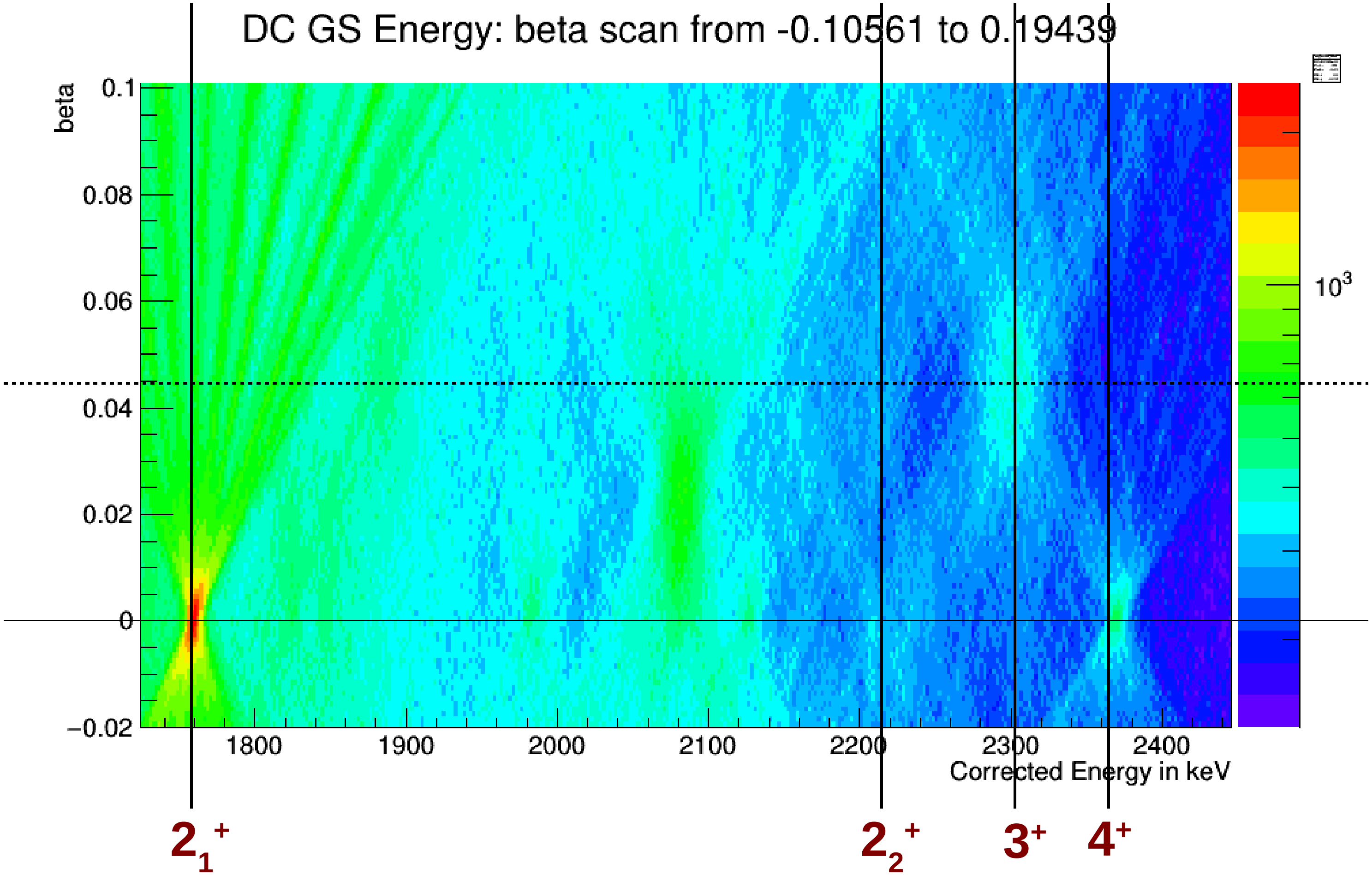




(M. Wiedeking et al., PRL **100** 152501 (2008))
(M. Petri et al., Phys. Rev. C **86** 044329 (2012))

Appendix: Carbon-16

Beta Scan for Target+Degrader Run:



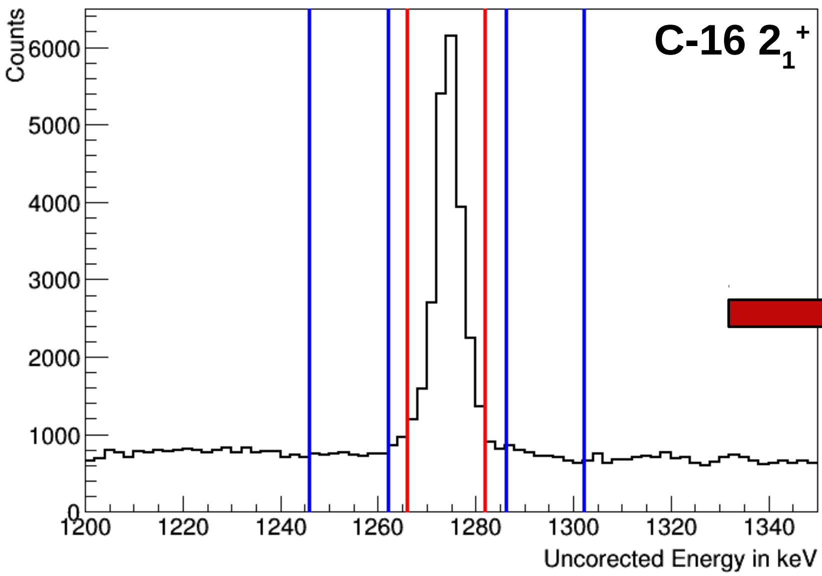
Appendix: Carbon-16

Create a realistic Geant4 Simulation:

- **Problem:** Initial beta distribution of C-16 is important but difficult to implement.
  (Unknown evap. distribution, stuck protons, efficiencies...)

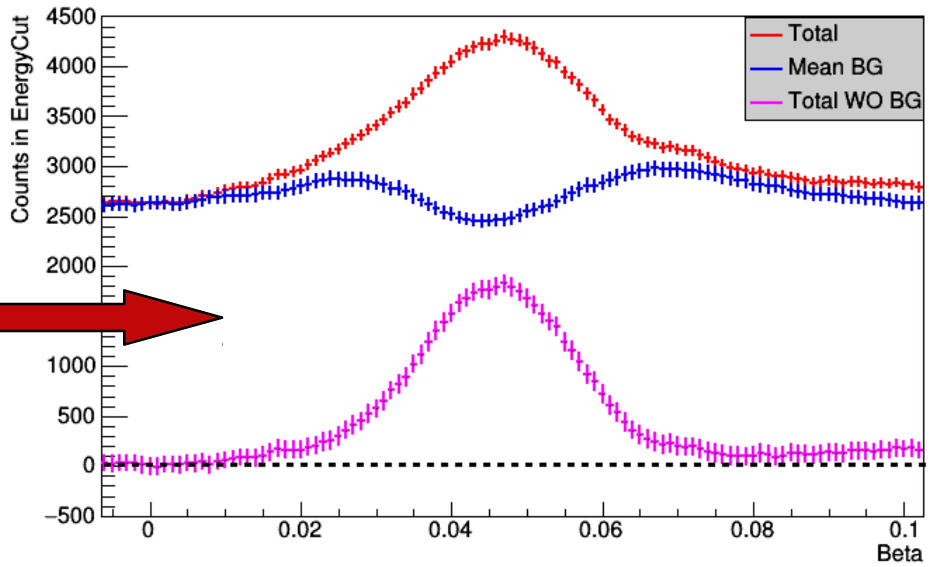
- **Solution:** Use experimental data as input beta distribution!

1) Degrader run for energy gates:



2) Thin target run for beta distribution:

Doppler correct for several betas & check energy



Appendix: Carbon-16

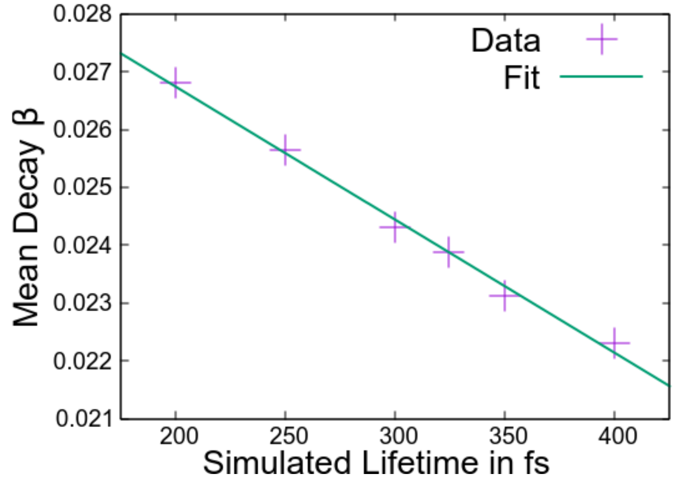
TECHNISCHE UNIVERSITÄT DARMSTADT

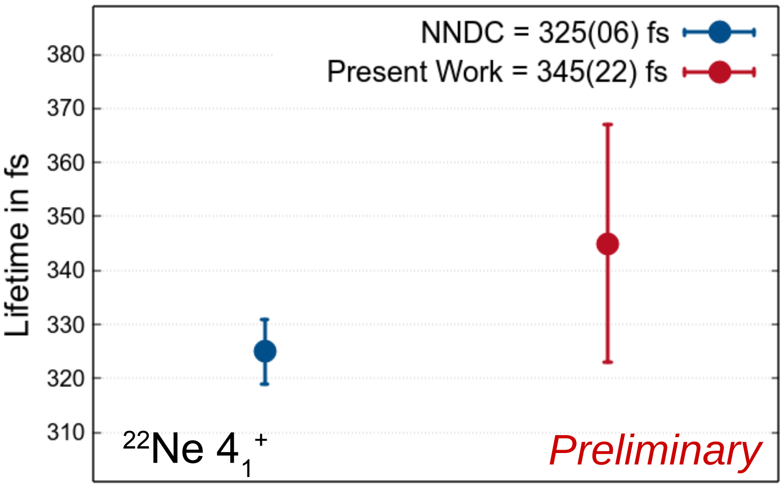
Test realistic Geant4 Simulation with Ne-22 4_1^+:

1) Extract initial beta distribution of Ne-22 mentioned before.

2) **In Geant4:** Generate excited Ne-22 isotope in a thin oxidation layer using the beta distribution from 1).

→ Do this for several lifetimes & extract mean decay beta.





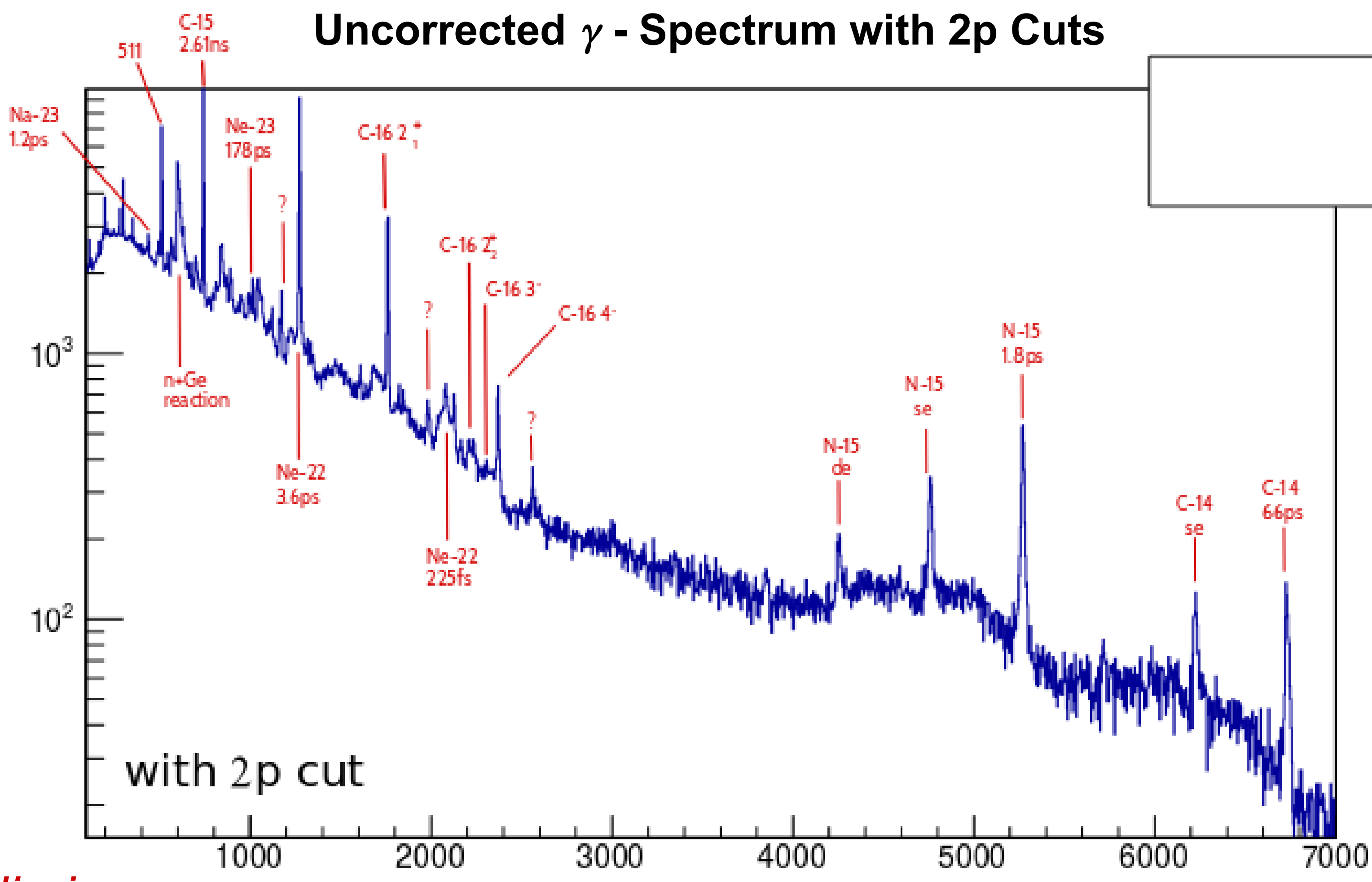
3) Extract experimental mean decay beta:

$$\overline{\beta}_{\text{Exp}} = 0.0234(3)$$

4) Calculate the lifetime for ^{22}Ne 4_1^+ using the results from 3) and 2).

Appendix: Carbon-16

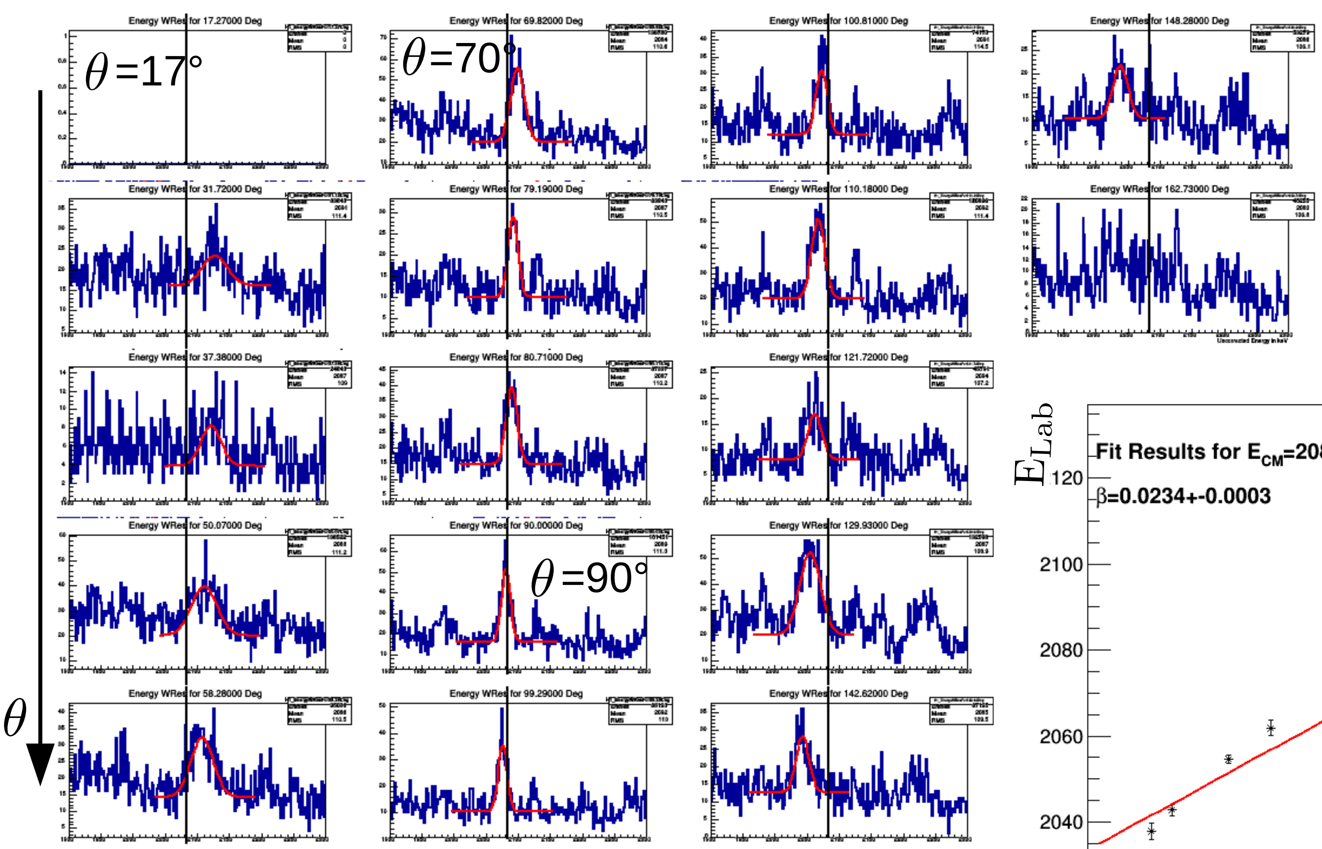
TECHNISCHE UNIVERSITÄT DARMSTADT



Preliminary

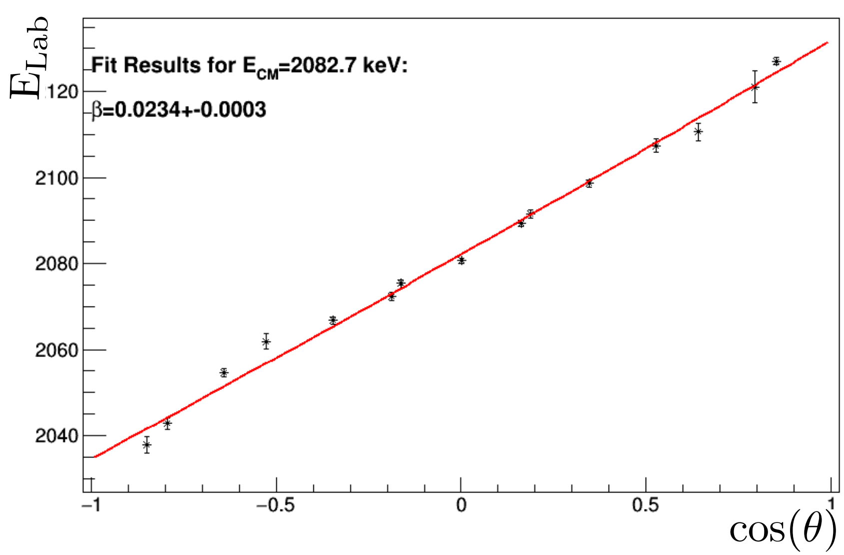
Appendix: Carbon-16

Movement of E_{Lab} for the experimental data for Ne-22 4+:



$$E_{\mathrm{Lab}} = E_{\mathrm{CM}} \frac{\sqrt{1-\beta^2}}{1-\beta\cos(\theta)}$$

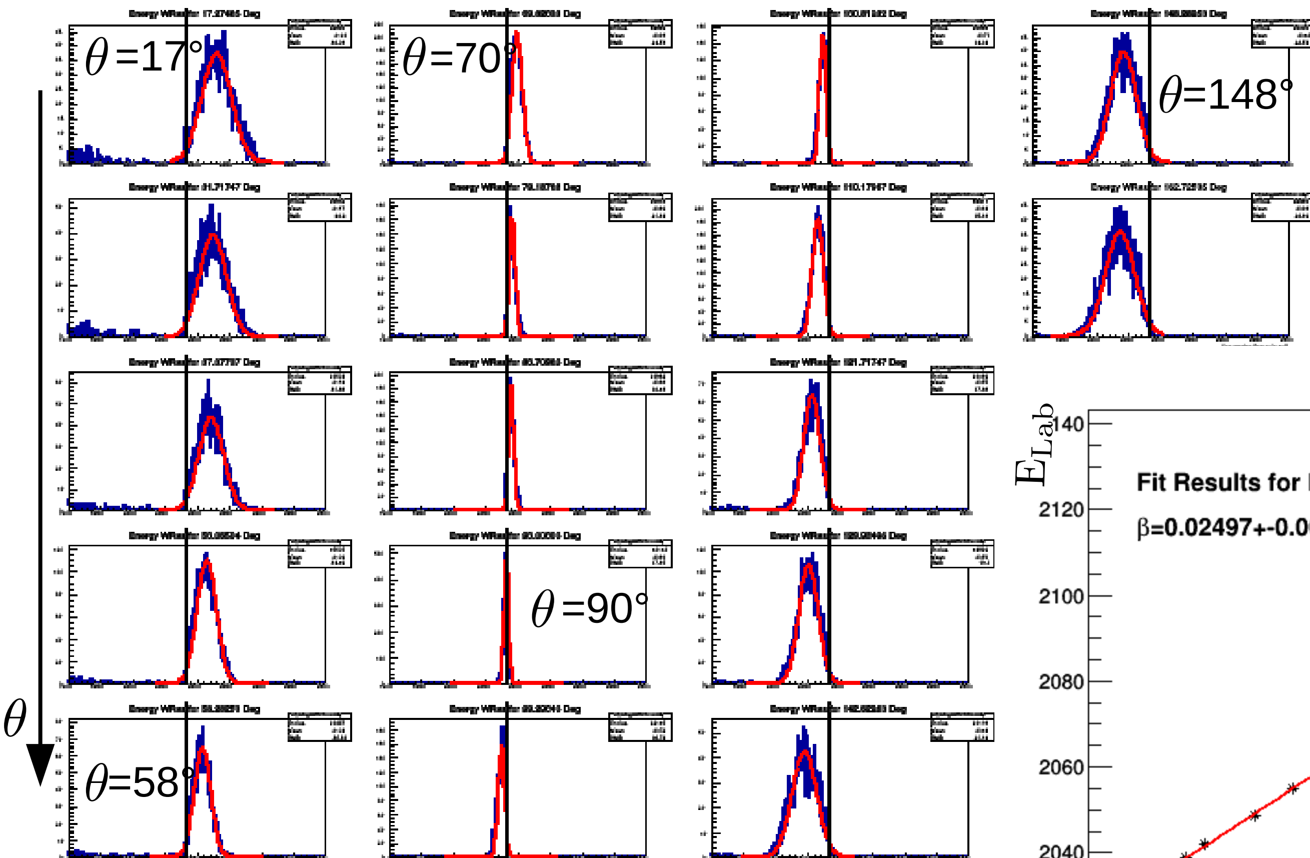
E_{Lab} vs cos(θ)



Preliminary

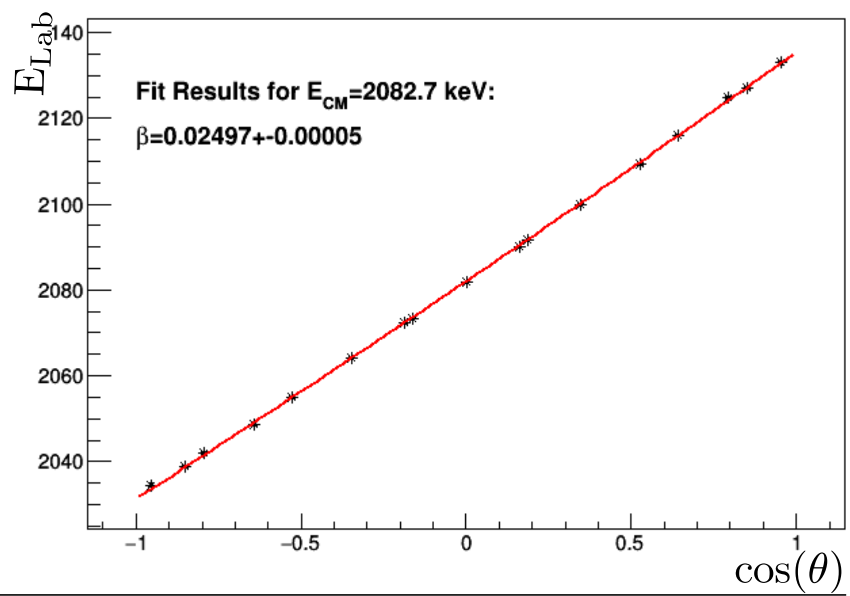
TECHNISCHE UNIVERSITÄT DARMSTADT

Movement of E_{Lab} for the simulation for Ne-22 4^+:



$$E_{\mathrm{Lab}} = E_{\mathrm{CM}} \frac{\sqrt{1-\beta^2}}{1-\beta\cos(\theta)}$$

E_{Lab} vs cos(θ)



Preliminary

Appendix: Carbon-12

arXiv:1709.07501v1 [nucl-ex] 21 Sep 2017

Reorientation-effect measurement of the first 2^+ state in ^{12}C: confirmation of oblate deformation

Downsides of this Latest $Q(2^+)$ Measurement:

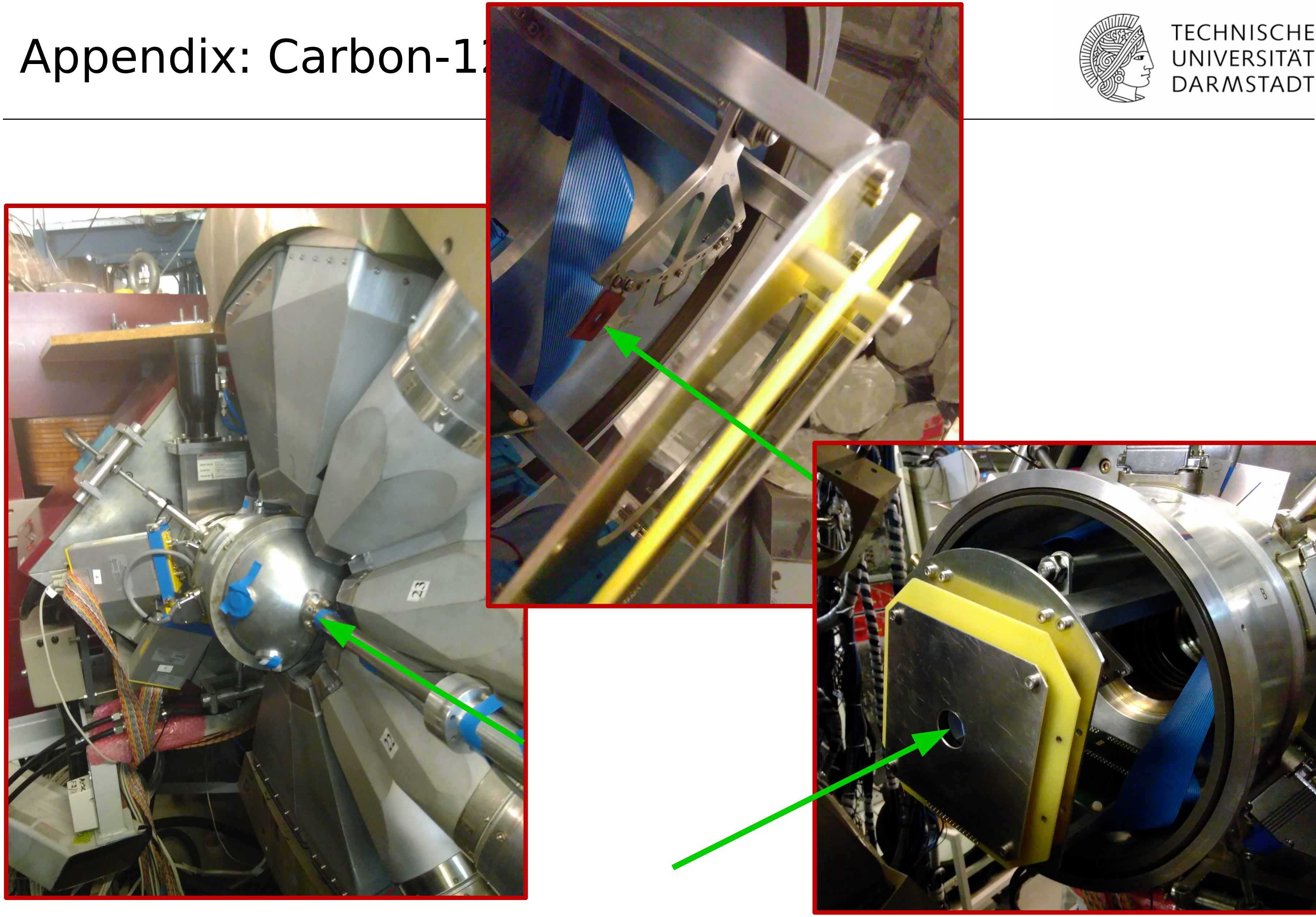
1) Measured C.S. relative to ^{194}Pt → Gamma-ray energy a few keV!
→ Large influence by changes in beam energy.

2) No sufficient gamma-ray efficiency calibration at 4 MeV.

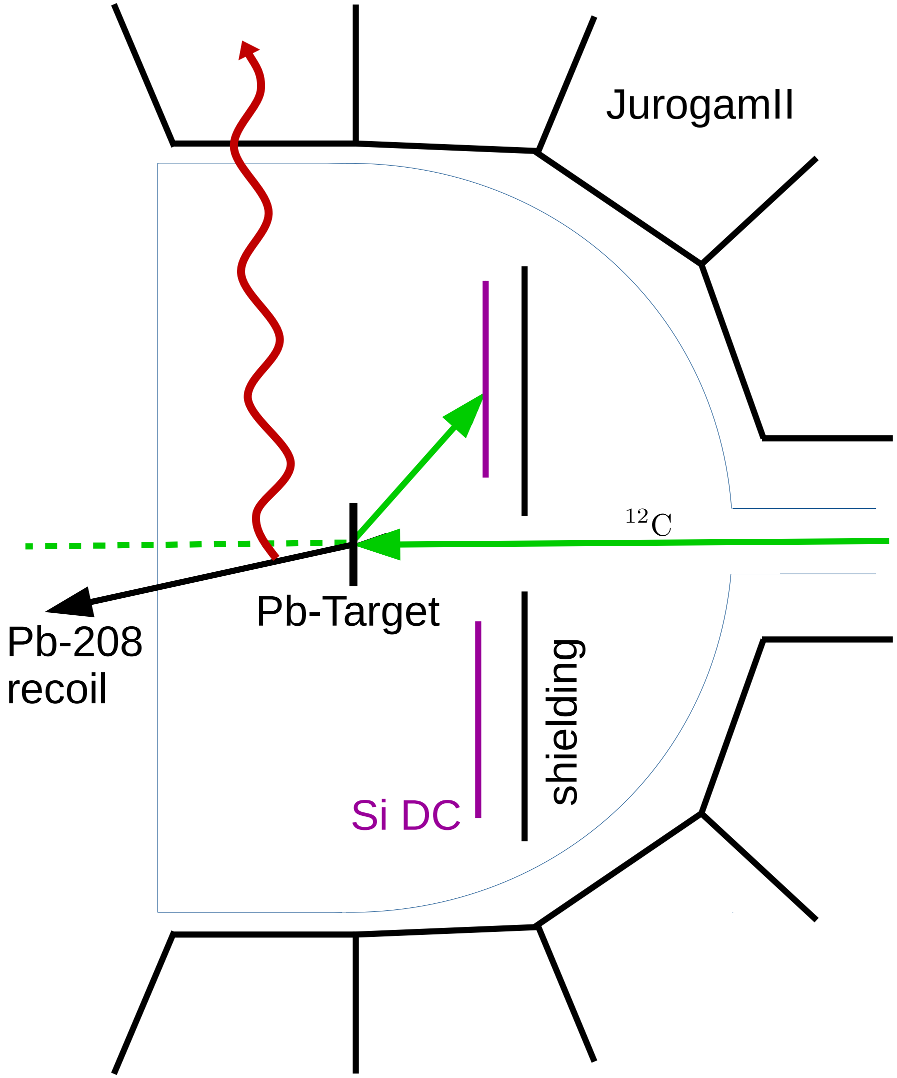
3) Measured only under forward angles → No sensitivity for $Q(2^+)$.

Result: $Q_s(2^+) = (+0.053 \pm 0.044)\,\mathrm{eb}$ 83% uncertainty

Appendix: Carbon-12



Appendix: Carbon-12

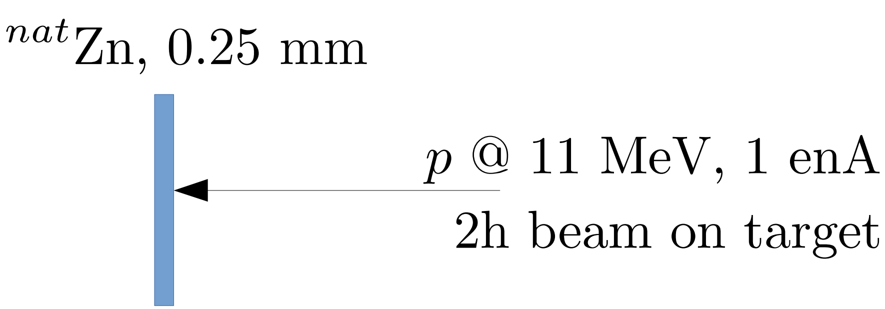


On-Line:

How to check that we really measure what we want to measure?

- **Problem:** Expect ~1600 gammas in 7 days for 2^+ state from C-12.
- **Better:** Look at the 3^- state from Pb-208. There we expect ~60 times more counts.
- Use information from backscattered C-12 to Doppler correct the Pb-208 gamma rays.

Appendix: Carbon-12



E_γ (keV) Helmer [16]	I_γ (rel.) Recommended
833.5324 (21)	15.93 (5)
1039.220 (3)	100.0 (3)
1333.112 (5)	3.175 (12)
1418.754 (5)	1.657 (8)
1508.158 (7)	1.497 (7)
1898.823 (8)	1.051 (8)
1918.329 (5)	5.368 (21)
2189.616 (6)	14.42 (5)
2422.525 (7)	5.085 (22)
2751.835 (5)	61.35 (23)
3228.800 (6)	4.082 (19)
3380.850 (6)	3.960 (19)
3422.040 (8)	2.314 (14)
3791.036 (8)[c]	2.941 (19)
4085.853 (9)	3.445 (18)
4295.224 (10)[c]	10.30 (8)[g]
4461.202 (9)	2.26 (3)
4806.007 (9)	5.03 (3)