Setup and Test of a Conversion Electron Spectrometer

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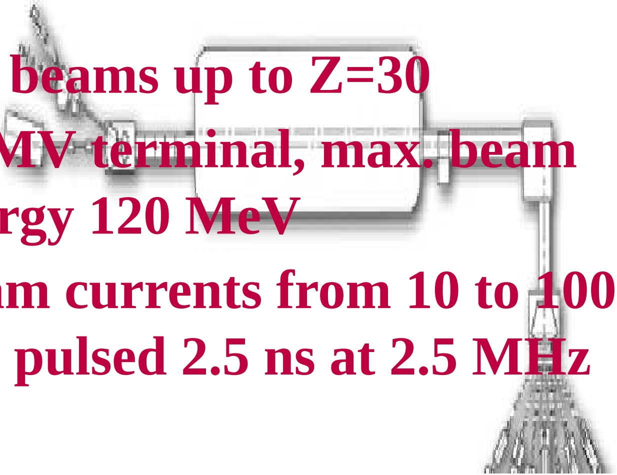
Contents

The Cologne Tandem-van de Graaf-generator



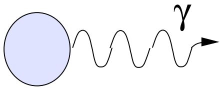
- **Ion beams up to Z=30**
- **10 MV terminal, max. beam energy 120 MeV**
- **Beam currents from 10 to 100 nA, pulsed 2.5 ns at 2.5 MHz**

The process of inner conversion

Electromagnetic transitions between excited nuclear states via either:

1. γ-Radiation or

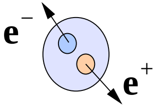
1.



The process of inner conversion

Electromagnetic transitions between excited nuclear states via either:

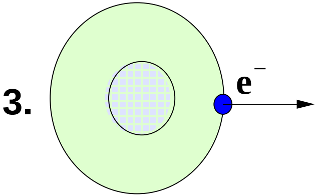
1. γ-Radiation or
2. Inner Pair Production
   above 1.022 MeV or

2.


The process of inner conversion

Electromagnetic transitions between excited nuclear states via either:

1. γ-Radiation or
2. Inner Pair Production above 1.022 MeV or
3. Shell interaction: Inner Conversion.



General transition probability

Why and Where is Conversion favoured?

$$\lambda(\sigma L) = \frac{P(\sigma L)}{\hbar\omega} = \frac{2(L+1)c}{\epsilon\hbar L[(2L+1)!!]^2}\left(\frac{\omega}{c}\right)^{2L+1}[m_{fi}(\sigma L)]^2$$

with σ: Multipolarity (E or M) and L: Multipolorder.

Conversion coefficient α

Definition

$$\alpha_i = \frac{\lambda_{e_i^-}}{\lambda_\gamma}$$

with $\lambda_{e_i^-}$: Transition probability for conversion electrons
and $\alpha = \sum_i \alpha_i \quad (i = K, L, M, ...)$

Total Transition Probability

$\lambda_t = \lambda_\gamma + \lambda_{e^-} = \lambda_\gamma(1 + \alpha)$
α is computed for all σ and L!

Calculation of α:

Extending the Nuclear and Continuum Wavefunktions with the Electronstates Wavefunktions:

$\psi_{\mathrm{i}} = \psi_{\mathrm{i,N}}\psi_{\mathrm{i,e^-}} \quad \text{und} \quad \psi_{\mathrm{f}} = \psi_{\mathrm{f,N}}\psi_{\mathrm{f,e^-}}$

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Conversion Coefficient:

$$\alpha(EL) \cong \frac{Z^3}{n^3}\left(\frac{L}{L+1}\right)\left(\frac{e^2}{4\pi\epsilon_0\hbar c}\right)^4\left(\frac{2m_e c^2}{E}\right)^{L+5/2}$$

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$$\alpha(ML) \cong \frac{Z^3}{n^3}\left(\frac{e^2}{4\pi\epsilon_0\hbar c}\right)^4\left(\frac{2m_ec^2}{E}\right)^{L+3/2}$$

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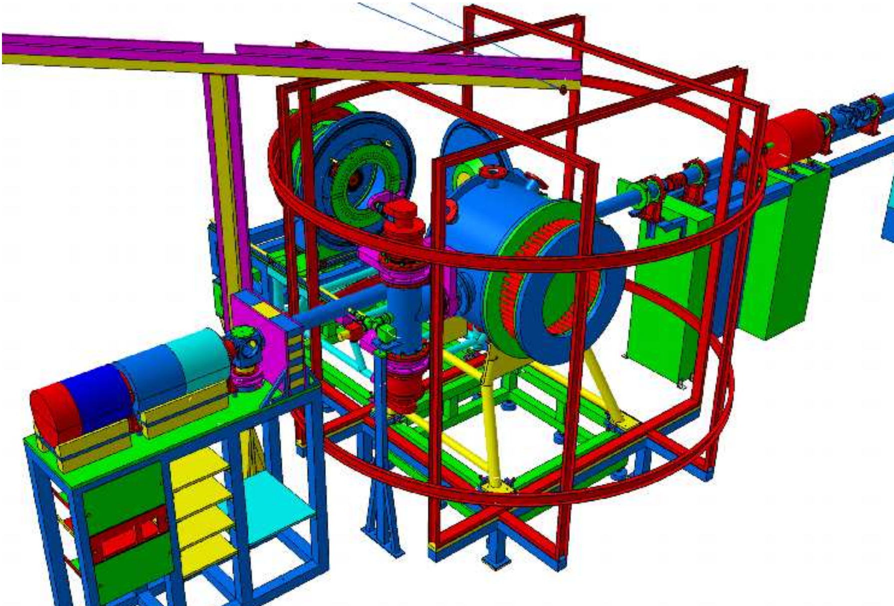
Conversion-coefficient dependencies:

Value of α increases with 4 variables:

- Stronger for high L
- Stronger for high Z
- Stronger for low E (contrast to Ge-counters)
- Stronger for low n (generally, not always)

Strong α: conversion is favoured process, very important for low E!

The magnetic Spectrometer



The magnetic Spectrometer, beamline

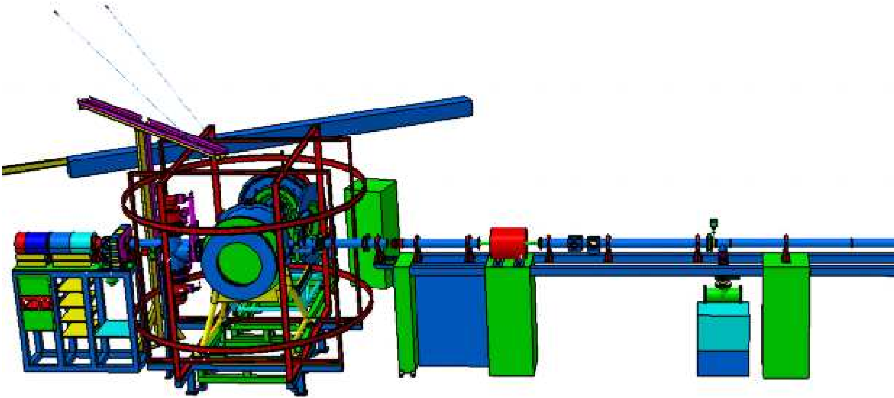
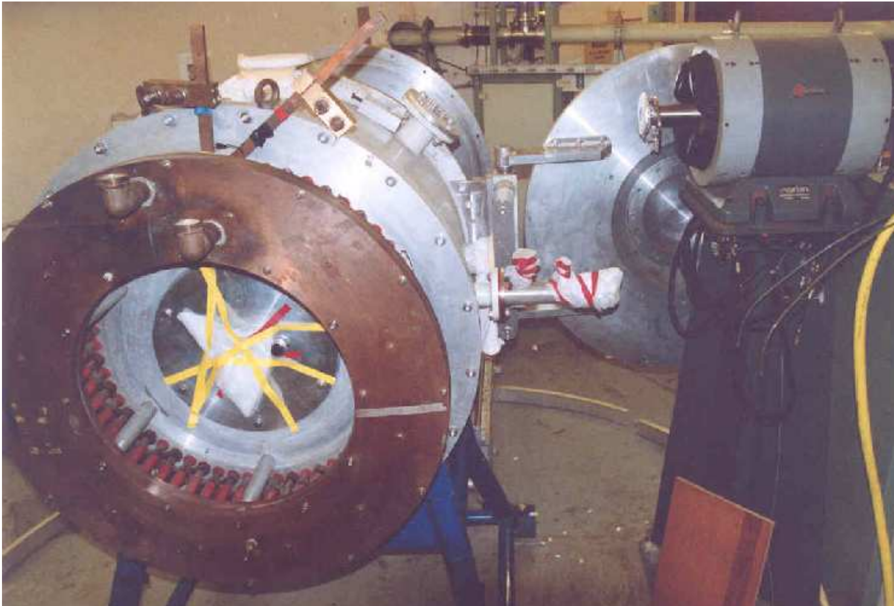
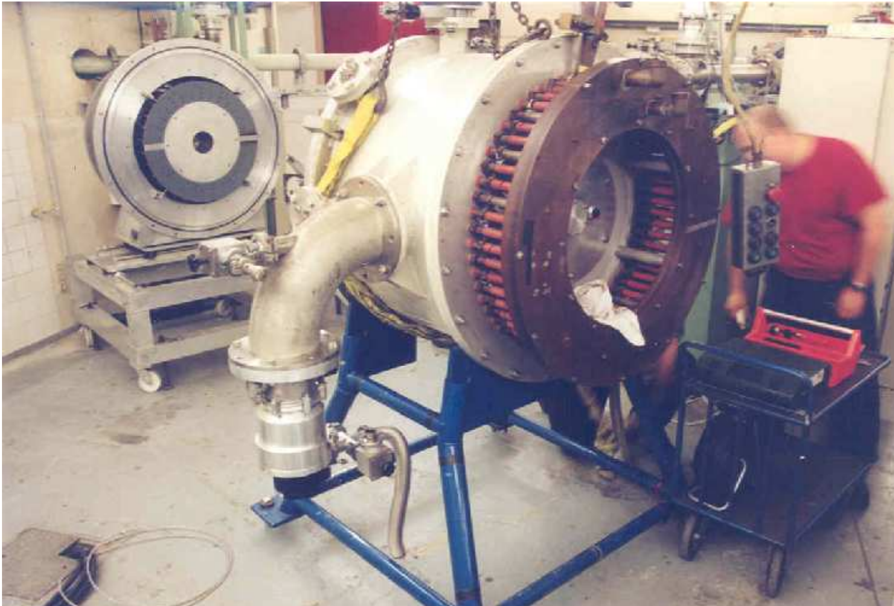


Abbildung: Double Orange setup at beamline R30, total

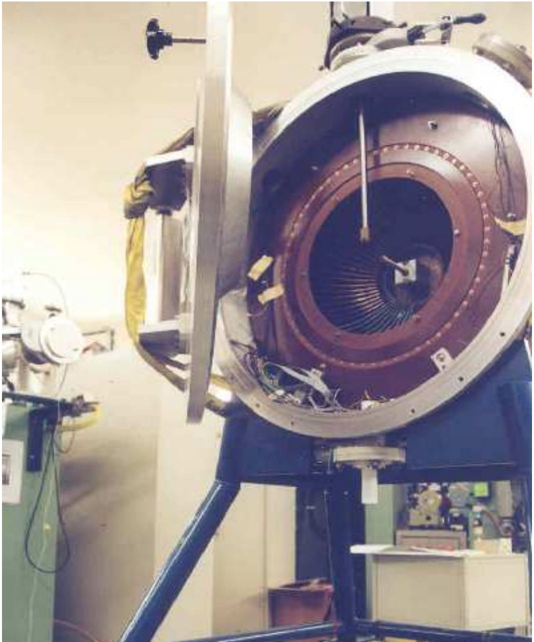
The magnetic Spectrometer, before setup



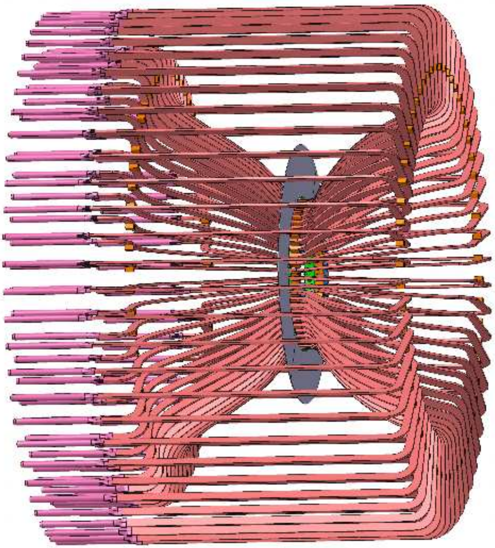
The magnetic Spectrometer, during setup



The magnetic Spectrometer, opened



The magnetic Spectrometer, toroid coil



Schematically

Resolution Variables:

- Target position
- Beamspot size on target
- Aperture width

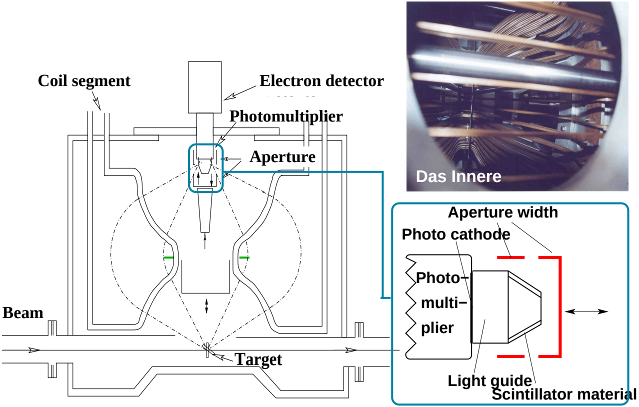


Abbildung: Setup of big Orange at beamline R30

Looking inside: adjustments

Other cruxial parameters:

- Earth’s magnetic field compensation
- Light leaks
- Scattered photons from bremsstrahlung

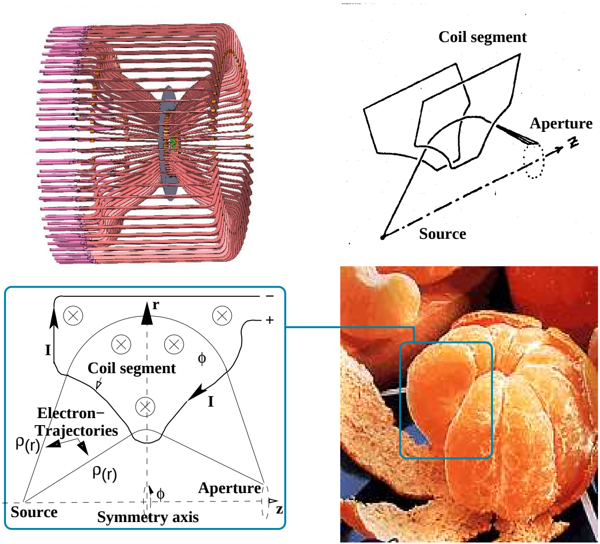


Abbildung: Coil segment

General properties

Electron in magnetic field

Electron in homogeneous magnetic field is forced into circular path.

$$F_{Lorentz} = evB$$

Electron’s mass generates centrifugal force.

$$F_{Centrifugal} = \frac{mv^2}{r}$$

Relative radius ρ(r):

$$H_z = H_r = 0 \quad ;$$
$$H_\phi = \frac{NI}{2\pi r} \quad ;$$
$$F_{\text{Lorentz}} = F_{\text{Centrifugal}}(\rho(r))$$
$$\Leftrightarrow ev\mu_0 H = \frac{mv^2}{\rho(r)}$$
$$\Rightarrow \rho(r) = \frac{2\pi pr}{\mu_0 eNI}$$

μ: Permeability, N: No of coils,
e: Elementary charge, $2\pi r = l$: Length of toroidal coil,
ρ: Relative radius, p: Electron momentum

$$\frac{\rho(r)}{r} = const.$$
$$\Rightarrow p(I) = aI + b$$

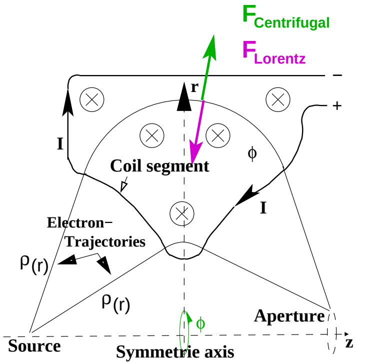


Abbildung: Coil segment with forces

Design steps, initial phase

1. Platform
2. Beam spot adjustment
3. Beamline: magnet, slits, beamdump
4. Cooling
5. Current generator tests
6. Cooling circuit stability observation
7. LabView control: automated stop at 42 °

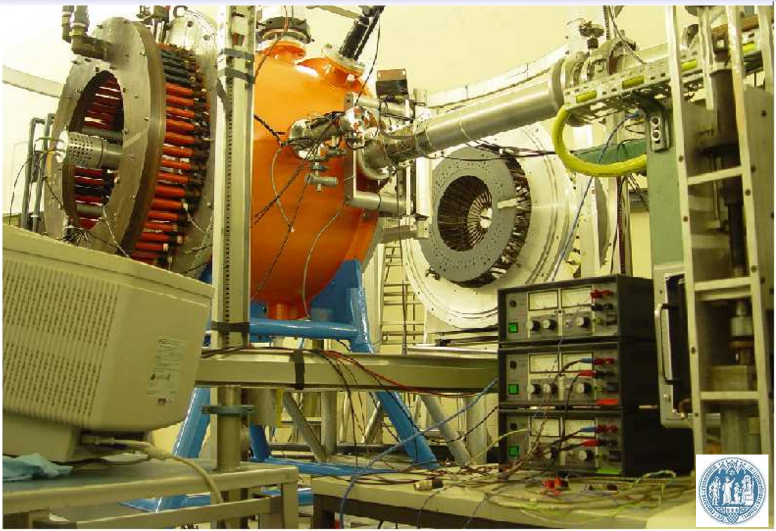
Design steps, final phase

1. Test measurements: singles, resolution, calibration
2. Delayed singles with pulsed beam → lifetime estimation

Outlook

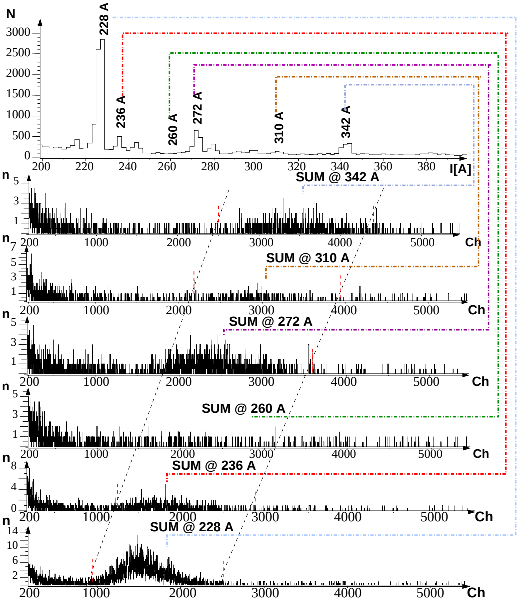
- Cold independent cooling circuit
- Double Orange: e^{-}–e^{-} coincidences → lifetimes, $\tau > 300$ ps, $\triangle\tau < 50$ ps
- e^{-}–γ coincidences (Ge- and $LaBr_3$(Ce)-scintillators),
  ($LaBr_3$(Ce): $\triangle$E = 4% and $\triangle$t = 180 ps)
  → lifetimes and coincident γ-ray spectra → level schemes

Final setup, Stage 1 (Singles)



’Sliding-window’ analysis: gates on e^--detector spectra

^{196}Pt(p, 2n)^{195}Au
@ 14 MeV
Linear or potential gates on plastic scintillator



^{133}Ba source spectrum

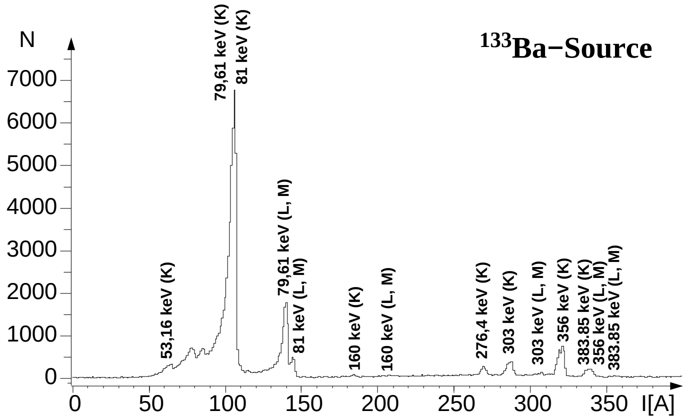
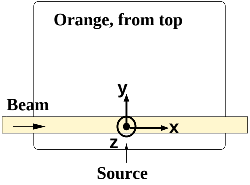
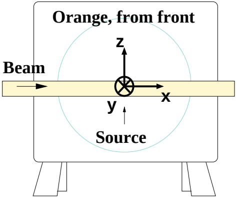


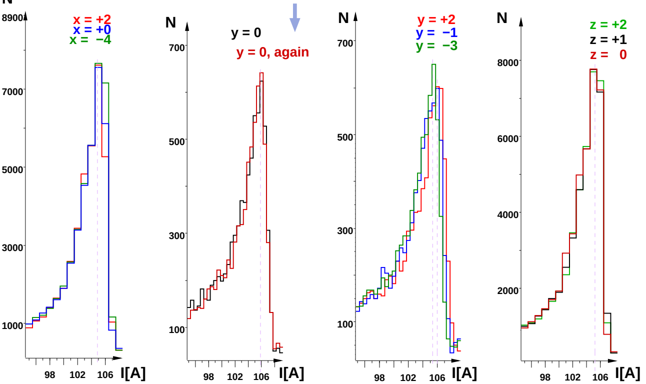
Abbildung: Off-beam: ^{133}Ba→^{133}Cs source current spectrum

^{133}Ba source position adjustment

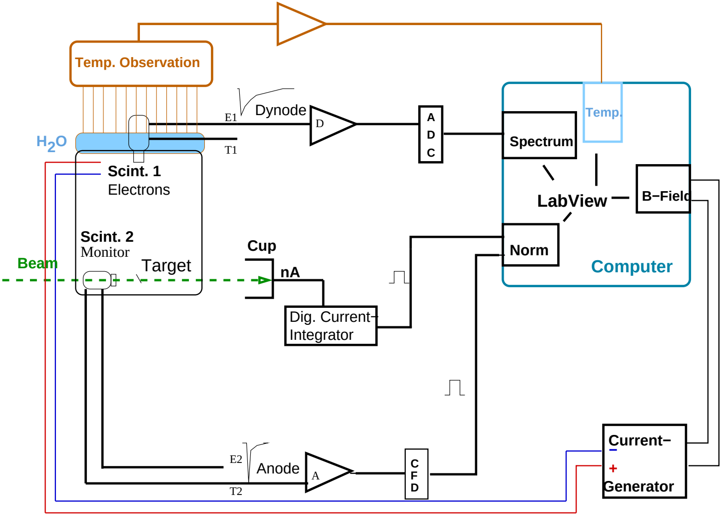




Peak pos. reproduced (off−beam)!!



Singles automated setup scheme



In-beam target position adjustment

- Peak position *not* reproduced!
- Resolution can be reproduced
- Target angle influence: width and shift

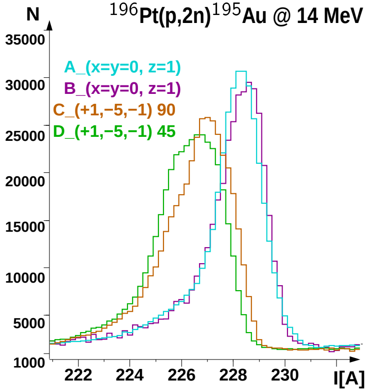
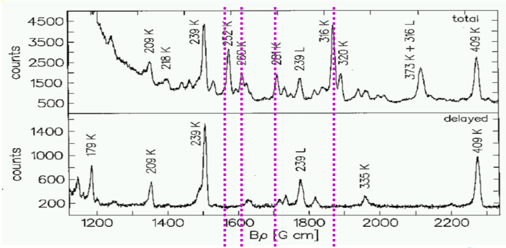


Abbildung: Target position and angle: difference in peak position and resolution

Comparison of delayed singles, pulsed beam

- Wendel et al.:
  $\triangle E \simeq$
  1.25 % (120 keV)
  and
  1.1 % (360 keV)
- Christen et al.:
  $\triangle E \simeq$
  0.95 % (172 keV)
  and
  1.61 % (306 keV)

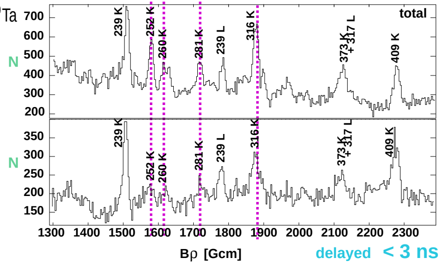
65



delayed = 3 ns

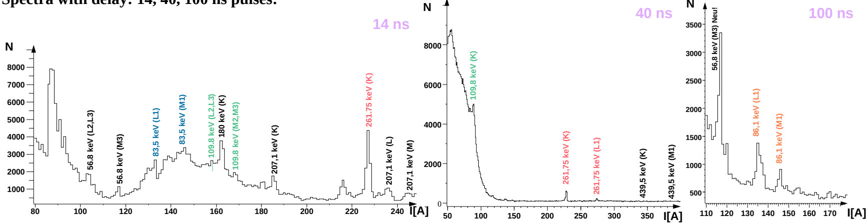
T. Wendel, J. Gröger, C. Günther,
Phys. Rev. C, , 014309 (2001).

^{180}Hf(p,n)^{180}Ta
@ 9,1 MeV



Known and new states in ^{195}Au, pulsed beam

Spectra with delay: 14, 40, 100 ns pulses:



Result	E_γ [keV]	Levels [keV]–>[keV]	Delay	Multipolarity
Reference Mult., L	● 261,75	261,79 $(\frac{5}{2}^+) \longrightarrow 0\ (\frac{3}{2}^+)$	14, 40 ns	M1+E2 (confirmed)
τ, Mult.?, L?	● 83,5	? $\longrightarrow$?	14, 40 ns	E3 ??
τ, Mult.?, L?	● 86,1	525,64 $(\frac{7}{2}^-) \longrightarrow$ 439,53 $(\frac{3}{2}, \frac{5}{2}^+)$	40, 100 ns	M2+E3 ?? , δ = 0,7
τ, Mult., L	● 109,8	549,38 $(\frac{7}{2}^+) \longrightarrow$ 439,53 $(\frac{3}{2}, \frac{5}{2}^+)$	14, 40 ns	Proposal : E2 ? (comp. to 86,1)

Abbildung: Analysis of ^{195}Au singles data

Lifetime measurement of 2_1^+ state in ^{166}Yb

Reaction: ^{164}Er(α,2n)^{166}Yb
@ 28 MeV

- Known
  $\tau = 1.789(90)$ ns
  (Bochev et al., Nuclear Physics A **267** (1976) 344, 358)
- New
  $\tau = 1.780(41)$ ns
  (Régis et al., Nucl. Instr. Meth. Phys. Res. Section **A** (2008))
- $\triangle\tau$ = statistical
  + magnetical (15 ps)
  + peak pos. shift (10 ps)

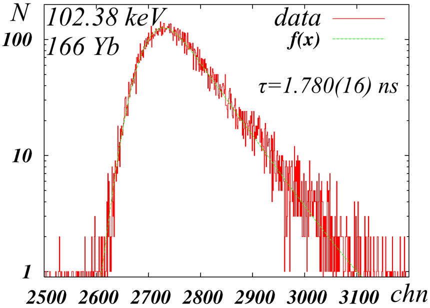
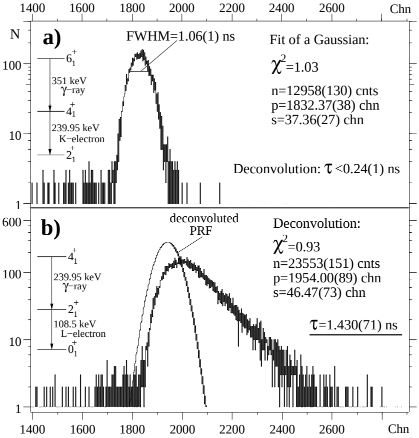


Abbildung: e^--e^- coincidence: lifetime of 2_1^+ state in ^{166}Yb

Lifetime measurement of 2_1^+ state in ^{176}W

Reaction: ^{169}Tm(^{11}B,4n)^{176}W
@ 53 MeV

- New e^--e^--lifetime:
  $\tau = 1.434(30)$ ns
  (Régis et al., Nucl. Instr. Meth. Phys. Res. Section **A** (2008))
- New e^--γ-lifetime:
  $\tau = 1.431(16)$ ns
  (Régis et al., Nucl. Instr. Meth. Phys. Res. Section **A** (2008))
- $\triangle\tau$ = statistical
  + magnetical (15 ps)
  + peak pos. shift (10 ps)



$LaBr_3(Ce)$ scintillator-Spectrum in Coincidence with 108.5 keV L-conversion electrons

Reaction: $^{169}Tm(^{11}B,4n)^{176}W$
@ 53 MeV

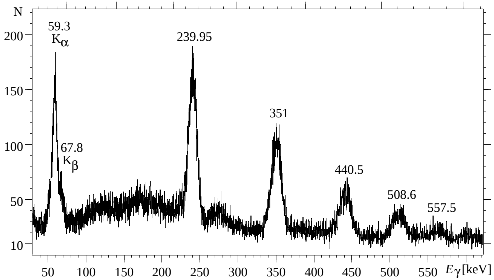
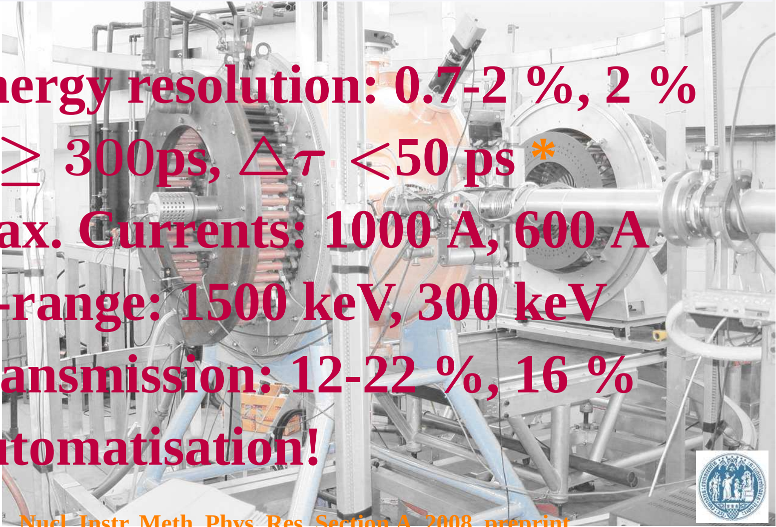


Abbildung: γ-spectrum in coincidence with $2_1^+ \rightarrow 0_1^+$ (converted) transition
($LaBr_3(Ce)$: $\triangle E$ = 4% and $\triangle t$ = 180 ps)

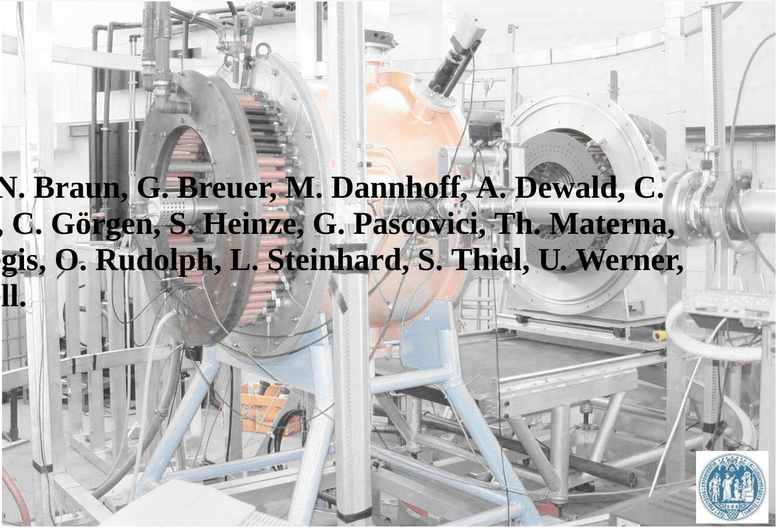
Measured characteristics



- **Energy resolution: 0.7-2 %, 2 %**
- $\tau \geq$ **300ps,** $\Delta\tau <$**50 ps ***
- **Max. Currents: 1000 A, 600 A**
- **E.-range: 1500 keV, 300 keV**
- **Transmission: 12-22 %, 16 %**
- **Automatisation!**

***Régis et al., Nucl. Instr. Meth. Phys. Res. Section A, 2008, preprint**

Credits



J. Jolie, N. Braun, G. Breuer, M. Dannhoff, A. Dewald, C. Fransen, C. Görgen, S. Heinze, G. Pascovici, Th. Materna, J.-M. Régis, O. Rudolph, L. Steinhard, S. Thiel, U. Werner, K. O. Zell.