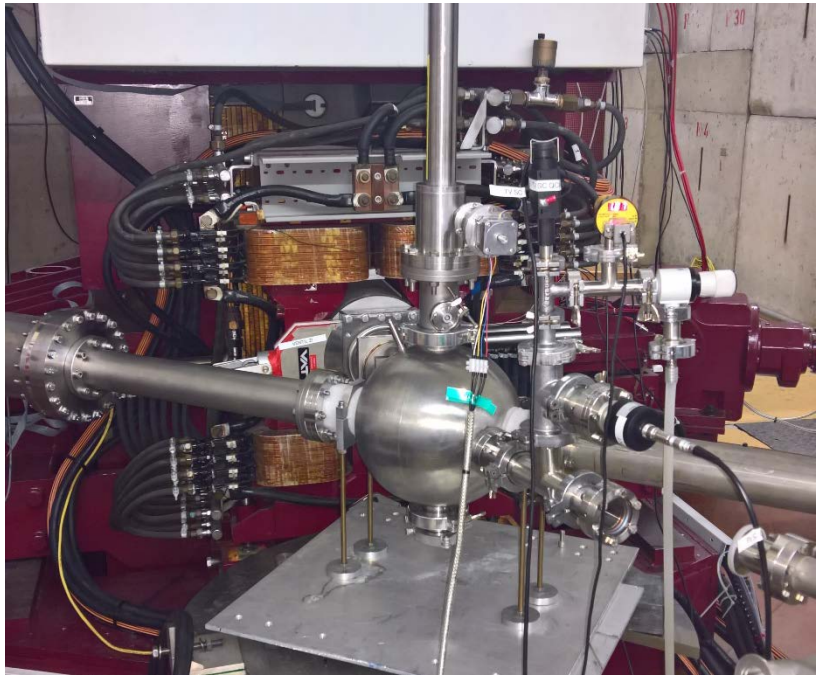
Report on Project A07
New EM Properties of Collective Excitations

N. Pietralla for

NP, J. Wambach, V. Yu. Ponomarev, T. Klaus, G. Steinhilber + SFB 1245

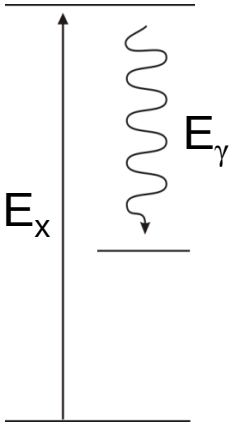
- **Principle of (e,e‘γ) Reactions**
- **Physics Motivation:**
  - Gamma-decay of GDR
  - Vorticity of Nuclear Currents
- **Theory Advances**
  - DWBA code for (e,e’γ)
- **Experimental Setup:**
  - Requirements
  - Data Acquisition
- **Summary and Outlook**

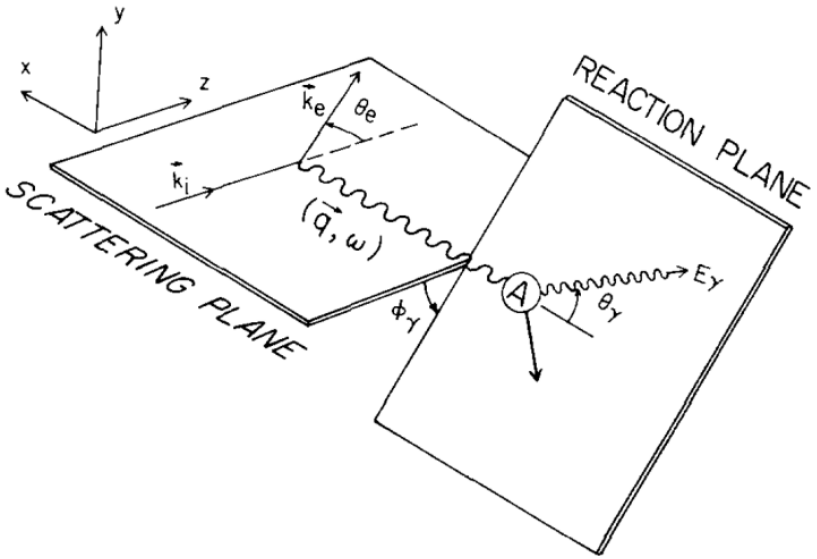


Supported by DFG within CRC 1245

Principle of (e,e'γ) Reactions

- Inelastic nuclear excitation by electron scattering and coincident detection of prompt γ-decay





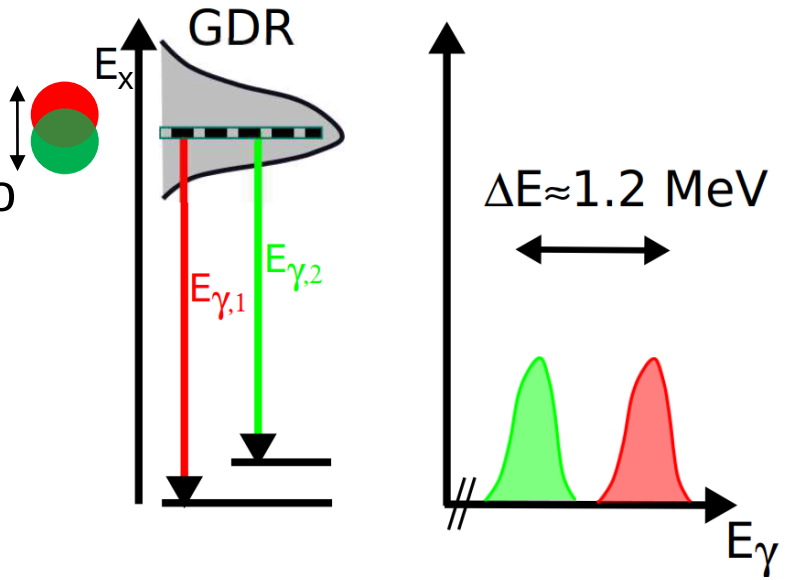
D.G. Ravenhall et al., Ann. Physics, 178 (1987)

Advantages of (e,e'γ)

- Pure e.m. interaction
- Exclusive reaction channel
- Selected excitation energy

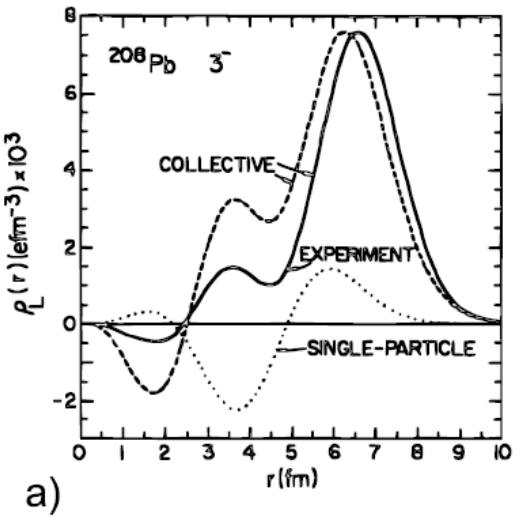
Spectroscopy Tool - Physics Motivation: Gamma Decay of the Giant Dipole Resonance

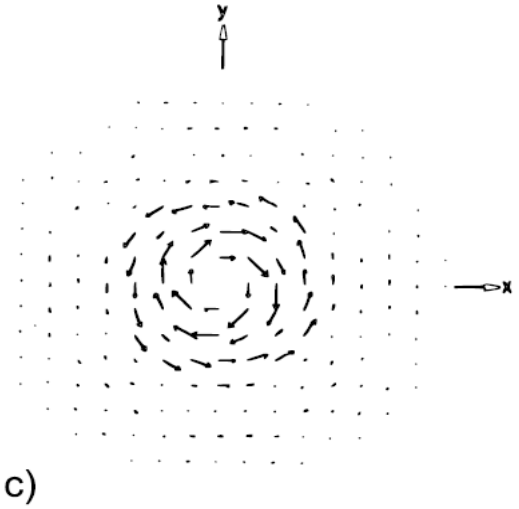
- GDR γ-decay branching to ground state: $\approx$ 1 %
  J. R. Beene et al., Phys. Rev. C (1990)
- Search for gamma-decay of GDR to intrinsic excitations
  V. Yu. Ponomarev et al., Nucl. Phys. (1992)
- Study variation of direct decay as a function of E_x
  $\rightarrow$ fine structure of GDR
- Study form factor of GDR in a clean way w/o multipole decomp. analysis



Proposal Project A07, Collaborative Research Centre 1245, (2015)

Access Tool - Physics Motivation: Vorticity of Nuclear Currents





D.G. Ravenhall and J. Wambach, Nucl. Phys. A 475, 468 (1987)

- Finite quantum system may exhibit confined currents with vorticity
- Vorticity strength contributes to transversal excitation amplitudes
- Polarization of excited states due to transversal/longitudinal interference
- Resulting rotation of γ distribution to study transversal form factors in (e,e'γ) reactions

Access Tool - Physics Motivation: Vorticity of Nuclear Currents

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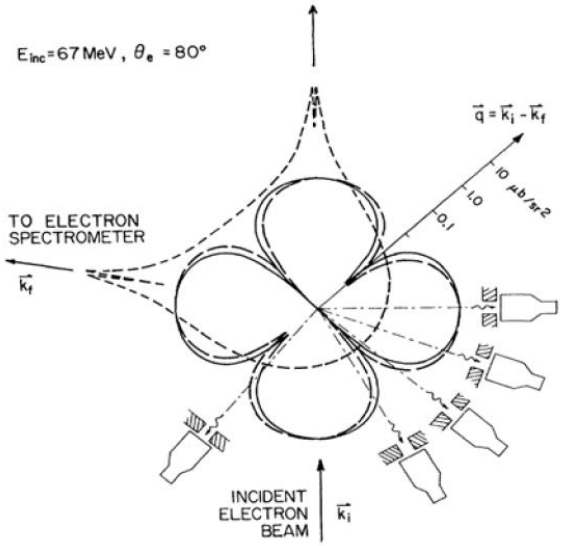
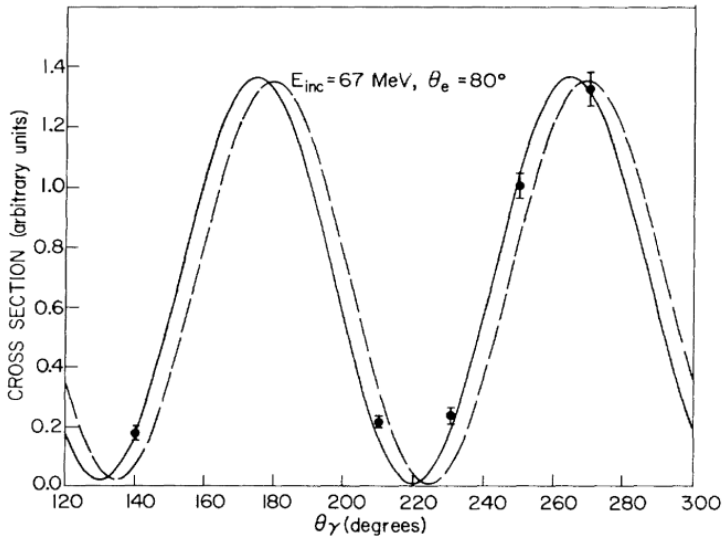
- Pioneering (e,e'γ) coincidence experiment
- Rotation of angular distribution of 2_1^+ in ^{12}C caused by nuclear currents





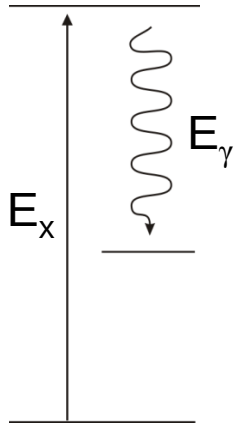
C. N. Papanicolas et al., Phys. Rev. Lett. **54** (1985)

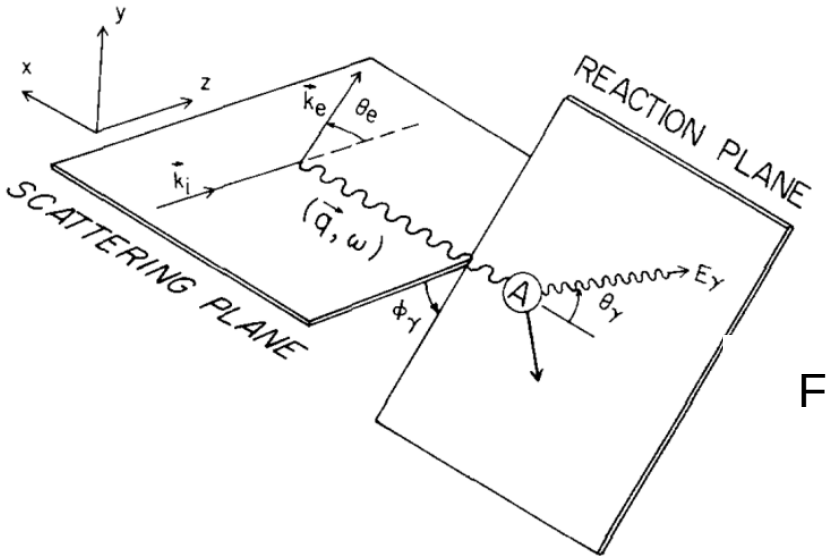
- Investigate rotation of angular distribution of $2_{1,2}^+$ and 3_1^- in ^{92}Zr

SFB 1245

Formalism of (e,e'γ) Reactions

- Inelastic nuclear excitation by electron scattering and coincident detection of prompt γ-decay





D.G. Ravenhall et al., Ann. Physics, 178 (1987)

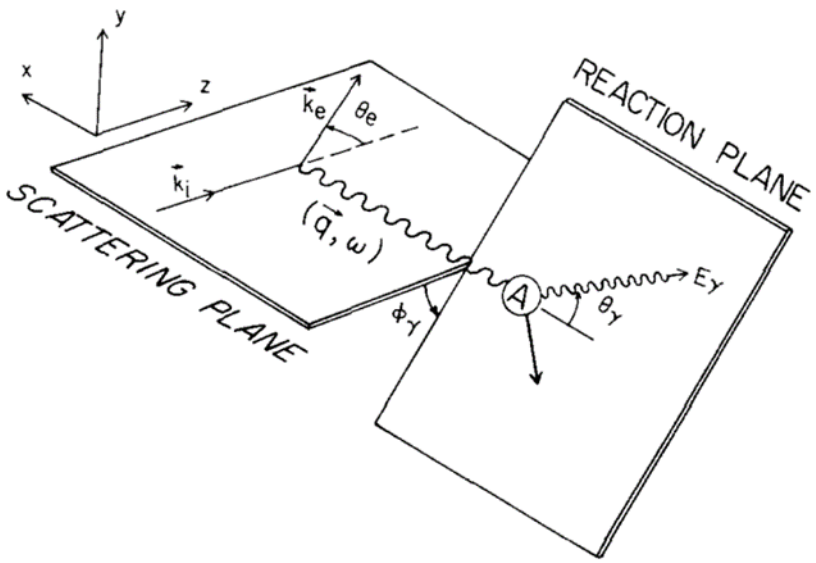
PWBA:

$$\frac{d^3\sigma}{d\omega d\Omega_e \Omega_\gamma} \sim V_L(\theta_e)\,|F_L(q)|^2\, V_L{}^{J_{ex}}(\theta_\gamma,\phi_\gamma) + V_T(\theta_e)\,|F_T(q)|^2\, V_T{}^{J_{ex}}(\theta_\gamma,\phi_\gamma) + V_{LT}(\theta_e)F_L(q)F_T(q)V_{LT}{}^{J_{ex}}(\theta_\gamma,\phi_\gamma)$$

$$F_L \propto \int_0^\infty \rho_\lambda(r) j_\lambda(qr) r^2 dr$$

$$F_T \propto \int_0^\infty \left\{ \sqrt{\lambda+1}\; j_{\lambda,\lambda-1}(r)\; j_{\lambda-1}(qr) + \sqrt{\lambda}\; j_{\lambda,\lambda+1}(r)\; j_{\lambda+1}(qr) \right\} r^2 dr$$

Formalism of (e,e'γ) Reactions



$$\frac{d^3\sigma_{\text{tot}}}{d\omega d\Omega_k d\Omega_f} = \frac{4\pi^2\omega^2 E_i E_f k_f}{k_i c^5}\frac{1}{2}\sum_{\zeta_i}\sum_{\zeta_f}\sum_{\lambda} \times \left|\frac{1}{c}M_{fi}^{\text{brems}} + \frac{1}{c}\left(M_{fi}^{(1)} + M_{fi}^{(2)}\right)\right|^2$$

- (e,e'γ) is a third-order process [~ α^3]
- It interferes coherently with bremsstrahlung

"***Bremsstrahlung background in inelastic electron-nucleus collisions***"
D.H. Jakubassa-Amundsen and A. Krugmann,
J. Phys. G: Nucl. Part. Phys. 44 (2017) 045103

- PWBA is insufficient for the description of bremsstrahlung for increasing momentum transfers in (e,e'γ) reactions

Formalism of (e,e'γ) Reactions, PWBA

$$\frac{d^3\sigma_{\mathrm{tot}}}{d\omega d\Omega_k d\Omega_f} = \frac{4\pi^2\omega^2 E_i E_f k_f}{k_i c^5}\frac{1}{2}\sum_{\zeta_i}\sum_{\zeta_f}\sum_{\lambda} \times \left|\frac{1}{c}M_{fi}^{\mathrm{brems}} + \frac{1}{c}\left(M_{fi}^{(1)} + M_{fi}^{(2)}\right)\right|^2$$

$$W_{fi} = \delta(E_f - E_i + \omega)M_{fi}$$

$$W_{fi}^{(1)} = i\frac{Z_T c^2}{4\pi\sqrt{\omega}}\delta(E_f - E_i + \omega)\frac{1}{\omega - E_x + i\Gamma_n/2} \times \sum_{M_n} A_{ni}^{\mathrm{exc}}(M_i, M_n)A_{fn}^{\mathrm{dec}}(M_n, M_f),$$

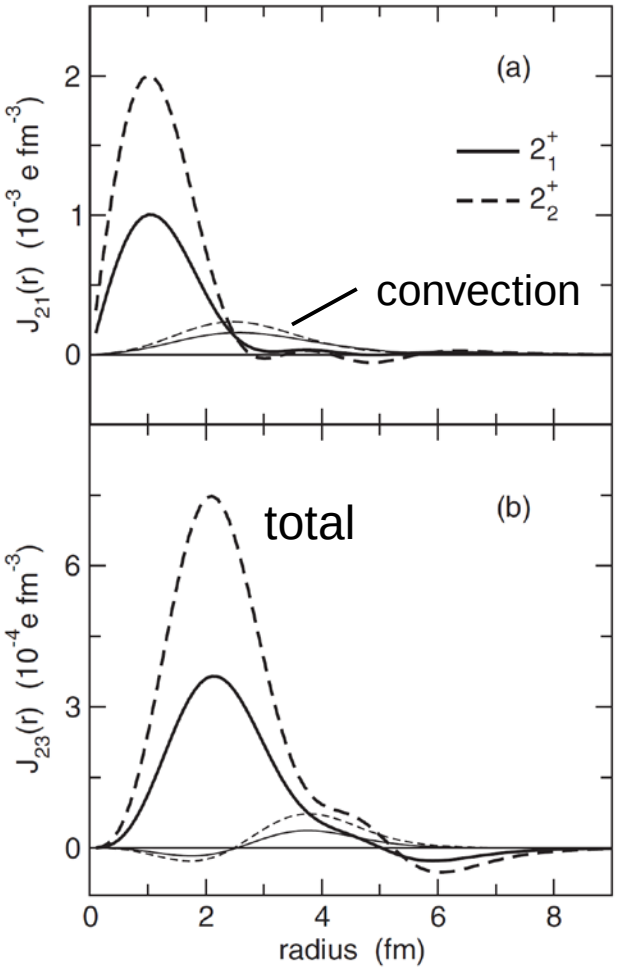
$$A_{fn}^{\mathrm{dec}}(M_n, M_f) = -4\pi i(J_n M_n L M | J_f M_f)\sum_{L'}(-i)^{L'} \times \sum_{\mu,\varrho}(\boldsymbol{e}_\varrho^+ \boldsymbol{\epsilon}_\lambda^*)(L'\mu 1\varrho | LM)Y_{L'\mu}^*(\hat{\boldsymbol{k}})R_{L'}(k)$$

$$R_{L'}(k) = \int_0^\infty r^2 dr\, j_{L'}(kr)J_{LL'}(r)$$

- ExDec (e,e'γ) amplitude interferes coherently with bremsstrahlung
- It has a resonant structure
- Its partial amplitudes depend on the transition currents

"***Coincident excitation and radiative decay in electron-nucleus collisions***"
D.H. Jakubassa-Amundsen and V. Yu. Ponomarev,
Phys. Rev. C 95 (2017) 024310.

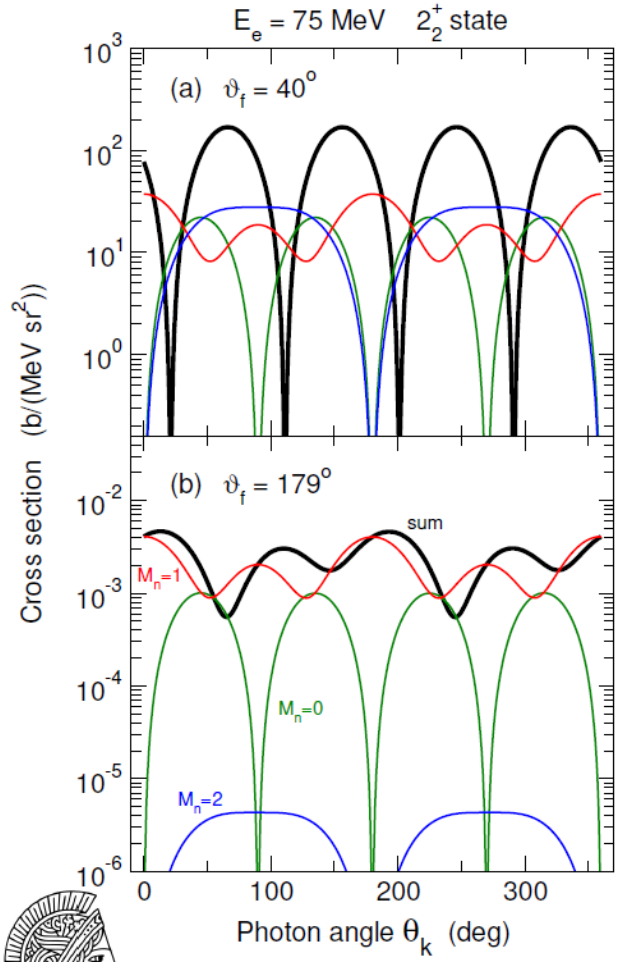
Prediction for (e,e'γ) Reactions on ^{92}Zr



- Transition current densities to the 2^+_1 and 2^+_2 states of ^{92}Zr as calculated in the QPM
- „Convection currents are small compared to magnetization currents“

"***Coincident excitation and radiative decay in electron-nucleus collisions***"
D.H. Jakubassa-Amundsen and V. Yu. Ponomarev,
Phys. Rev. C 95 (2017) 024310.

Prediction for (e,e'γ) Reactions on ^{92}Zr, PWBA



$$\frac{d^3\sigma_{(M_n=0)}}{d\omega d\Omega_k d\Omega_f} \sim B_0 \sin^2 2\theta_k$$

$$\frac{d^3\sigma_{(M_n=\pm1)}}{d\omega d\Omega_k d\Omega_f} \sim A_{\pm1} \cos^2 \theta_k + B_{\pm1} \cos^2 2\theta_k$$

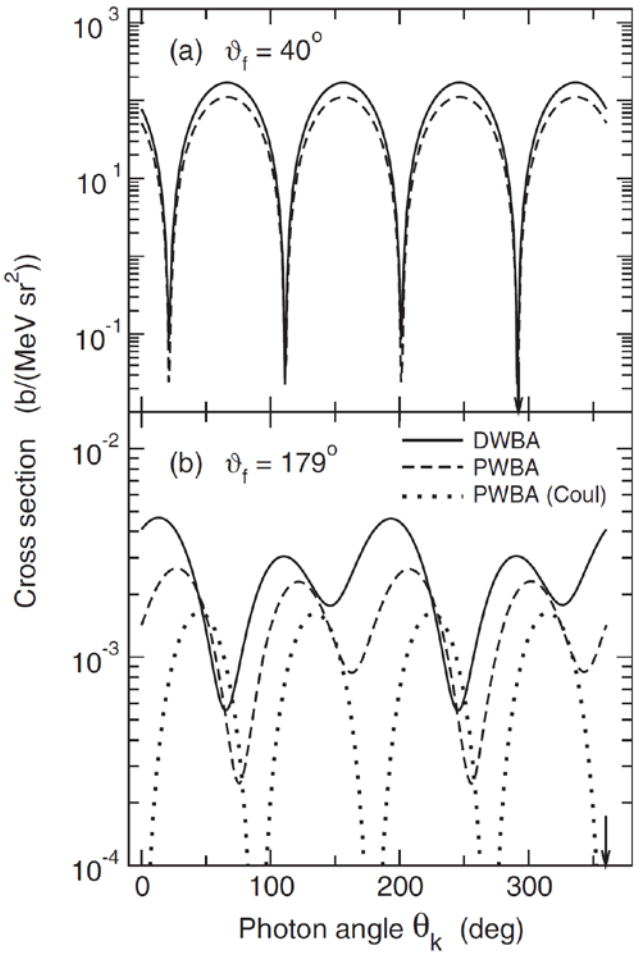
$$\frac{d^3\sigma_{(M_n=\pm2)}}{d\omega d\Omega_k d\Omega_f} \sim A_{\pm2} \sin^2 \theta_k + B_{\pm2} \sin^2 2\theta_k$$

$$B_{\pm2} << 1$$

V. Yu. Ponomarev

Prediction for (e,e'γ) Reactions on ^{92}Zr, DWBA

$$d^3\sigma / d\omega\, d\Omega_k d\Omega_f$$



- Triple-differential cross section for the 2^+_2 decay excited in 75 MeV (e,e'γ) reaction with electron scattered to 40^o (a) and 179^o (b) as a function of photon angle.
- Large effect at small cross section

"***Coincident excitation and radiative decay in electron-nucleus collisions***"
D.H. Jakubassa-Amundsen and V. Yu. Ponomarev,
Phys. Rev. C 95 (2017) 024310.

Theory Advances in A07

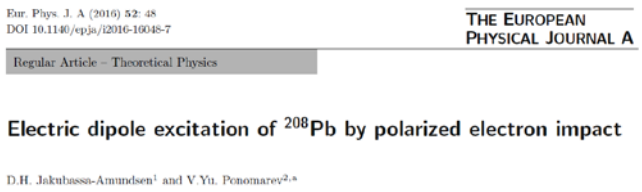
TECHNISCHE UNIVERSITÄT DARMSTADT

- Study of magnetization and convection currents in (e,e‘) reactions in DWBA

- Study of bremsstrahlung as a competitor to resonant ExDec (e,e‘γ) reaction

- Establishment of a DWBA code for (e,e’γ) reactions and application to ^{92}Zr

- Prediction for (e,e’γ) reactions on the PDR of ^{140}Ce in DWBA


Eur. Phys. J. A (2016) 52: 48
DOI 10.1140/epja/i2016-16048-7

THE EUROPEAN PHYSICAL JOURNAL A

Regular Article – Theoretical Physics

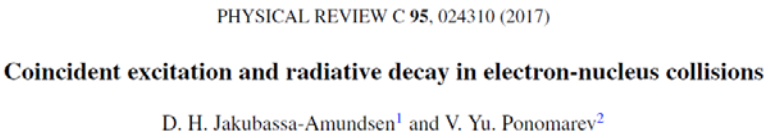
Electric dipole excitation of ^{208}Pb by polarized electron impact

D.H. Jakubassa-Amundsen[1] and V.Yu. Ponomarev[2,a]


IOP Publishing
J. Phys. G: Nucl. Part. Phys. 44 (2017) 045103 (8pp)
Journal of Physics G: Nuclear and Particle Physics
https://doi.org/10.1088/1361-6471/aa5778

Bremsstrahlung background in inelastic electron–nucleus collisions

D H Jakubassa-Amundsen[1] and A Krugmann[2]


PHYSICAL REVIEW C **95**, 024310 (2017)

Coincident excitation and radiative decay in electron-nucleus collisions

D. H. Jakubassa-Amundsen[1] and V. Yu. Ponomarev[2]

Eur. Phys. J. A (prepared on invitation)

SFB 1245

Establishment of Experimental Set-up

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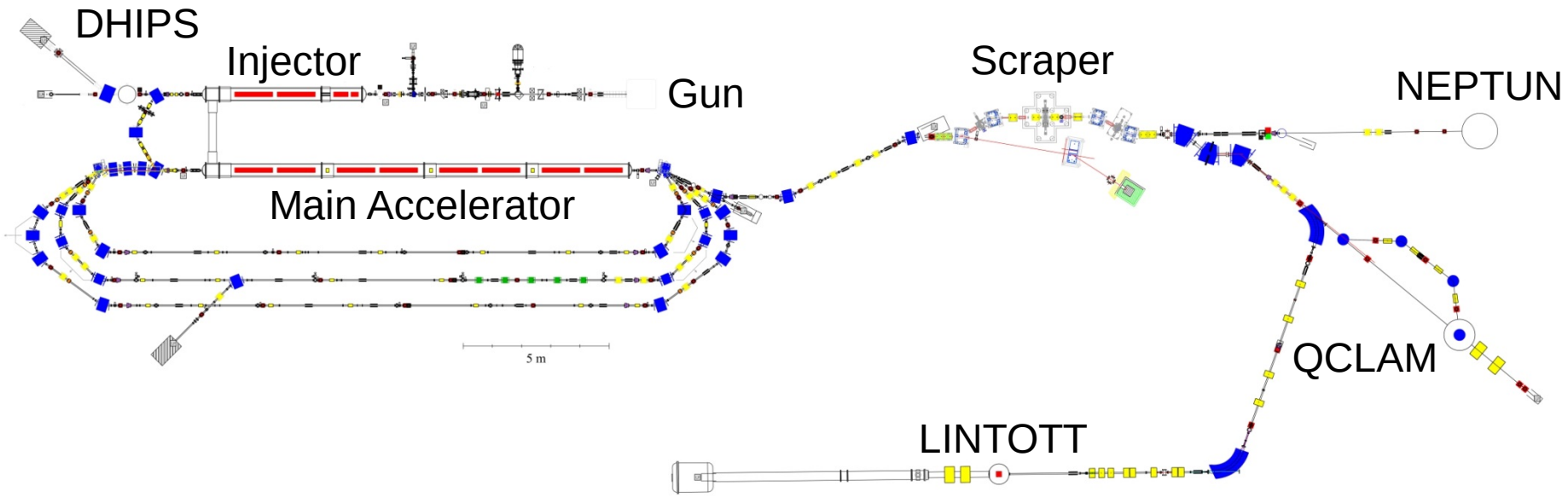
- Halo-free electron beam
- Q-CLAM coincidence spectrometer
- Target area
- Gamma spectrometer
- Coincidence DAQ

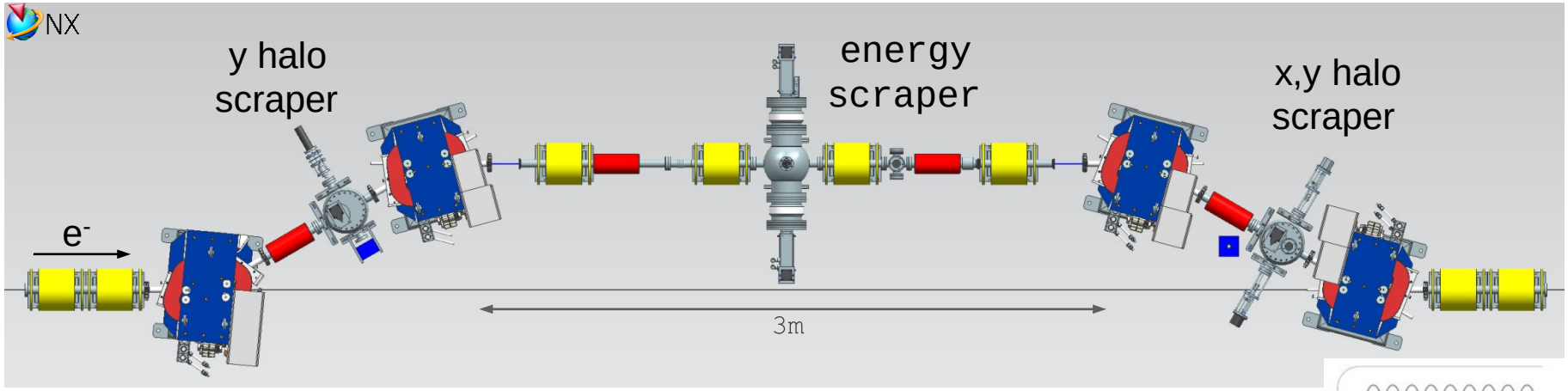
Halo-Free Electron Beam @ S-DALINAC



M. Arnold, Doctoral Thesis, TU Darmstadt (2016)

Also supported by GRK 2128

Halo-Free Electron Beam @ S-DALINAC



L. Jürgensen, Doctoral Thesis (2018)

High-Acceptance Spectrometer: Q-CLAM

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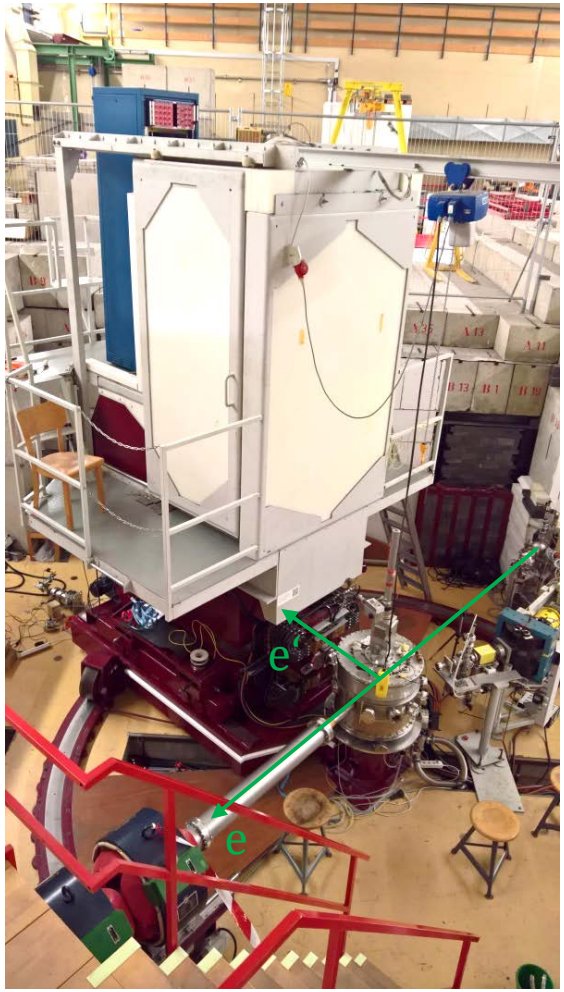
QCLAM Spectrometer

- Max. momentum: 220 MeV/c
- Momentum acceptance: $\Delta p/p = \pm 10$ %
- Solid angular acceptance: 35 msr
- Energy resolution: $\Delta E/E \approx 5 \cdot 10^{-4}$
- Scattering angles:
  25°-155°, 180°

⇨ Well suited for coincidence experiments



Refurbishment of Q-CLAM Spectrometer

(together with A01, A03, B02, B03 and AccelencE)

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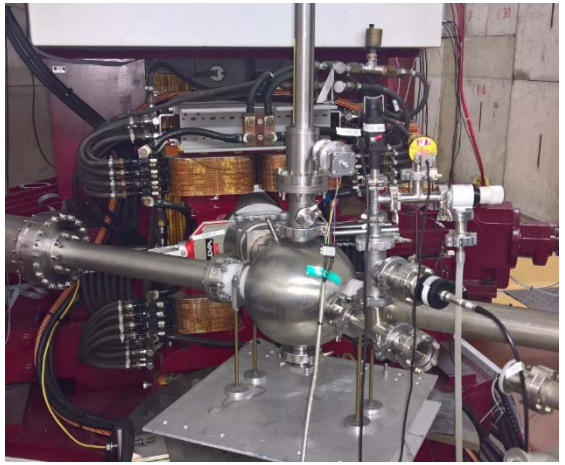
- Wiring of Multi-Wire Drift Chambers
  (A. D'Alessio & Q-CLAM group)
- Completion of vaccum system
- Installation target chamber and its adapter to Q-CLAM
- Remote control of target ladder



QCLAM Sieve Slit Measurement

(together with A01, A03, B02, B03 and AccelencE)

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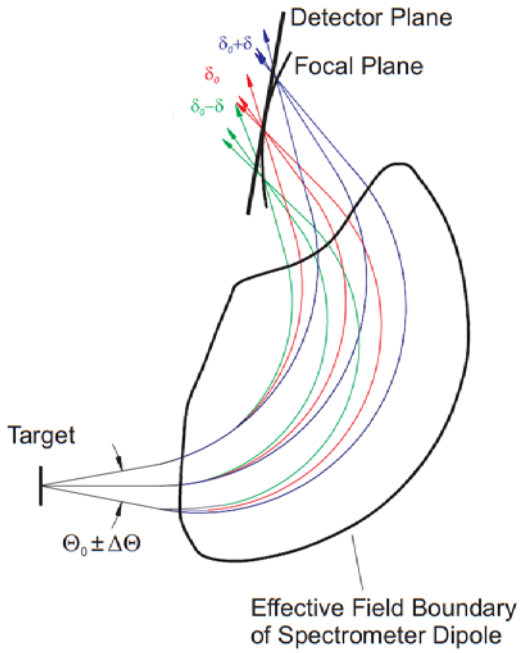
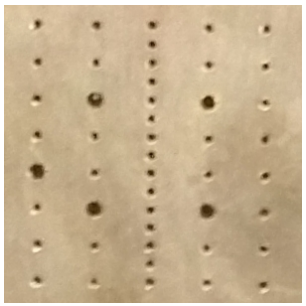
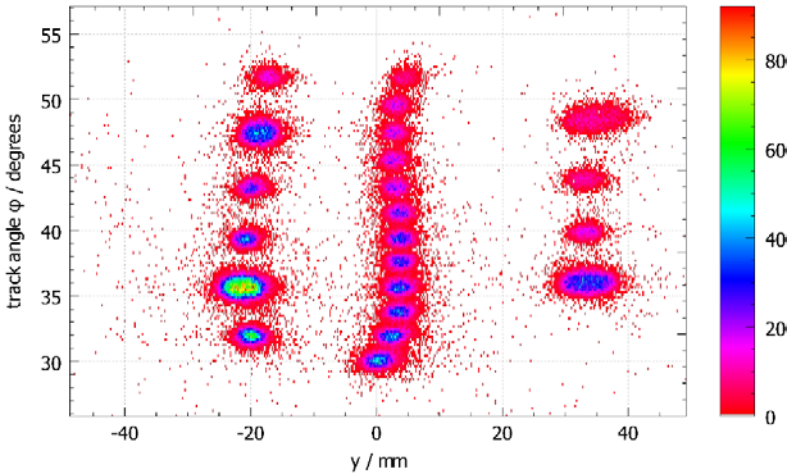
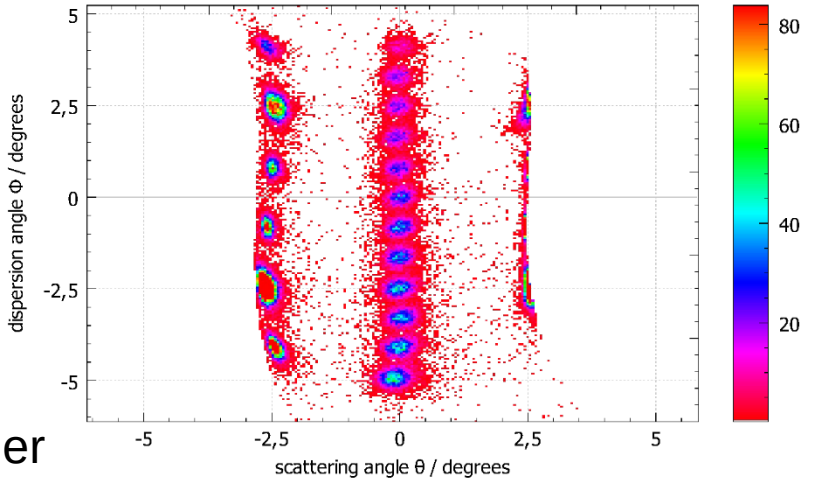
- Correction of curved focal plane









M. Singer

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QCLAM ^{12}C Measurement

(together with A01, A03, B02, B03 and AccelencE)

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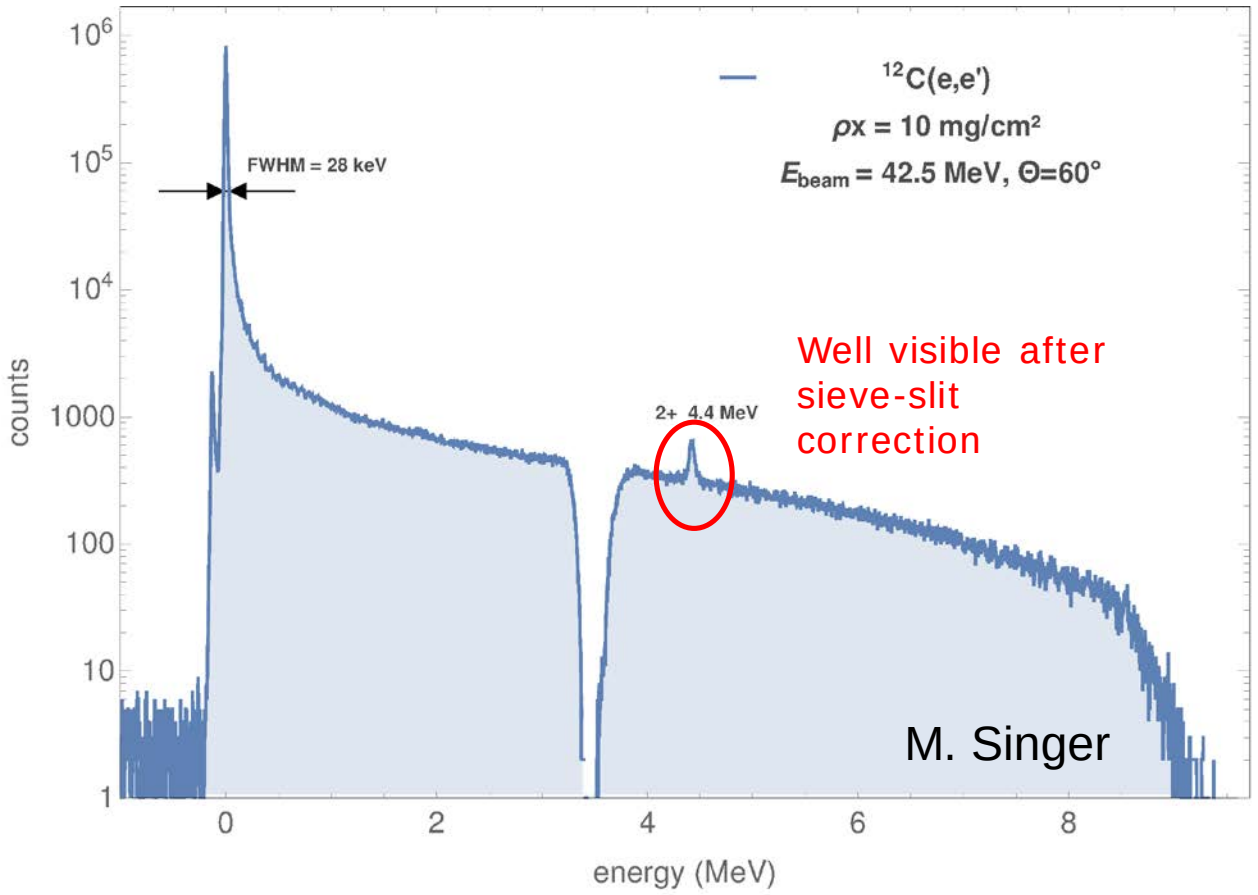
- Energy resolution: $6.6 \cdot 10^{-4}$

(best value so far: $7.6 \cdot 10^{-4}$, Dissertation Hummel, 1992)

- Gap at ~3.5 MeV: 4 broken wires

- New MWDCs are under construction in AccelencE (A. D'Alessio)



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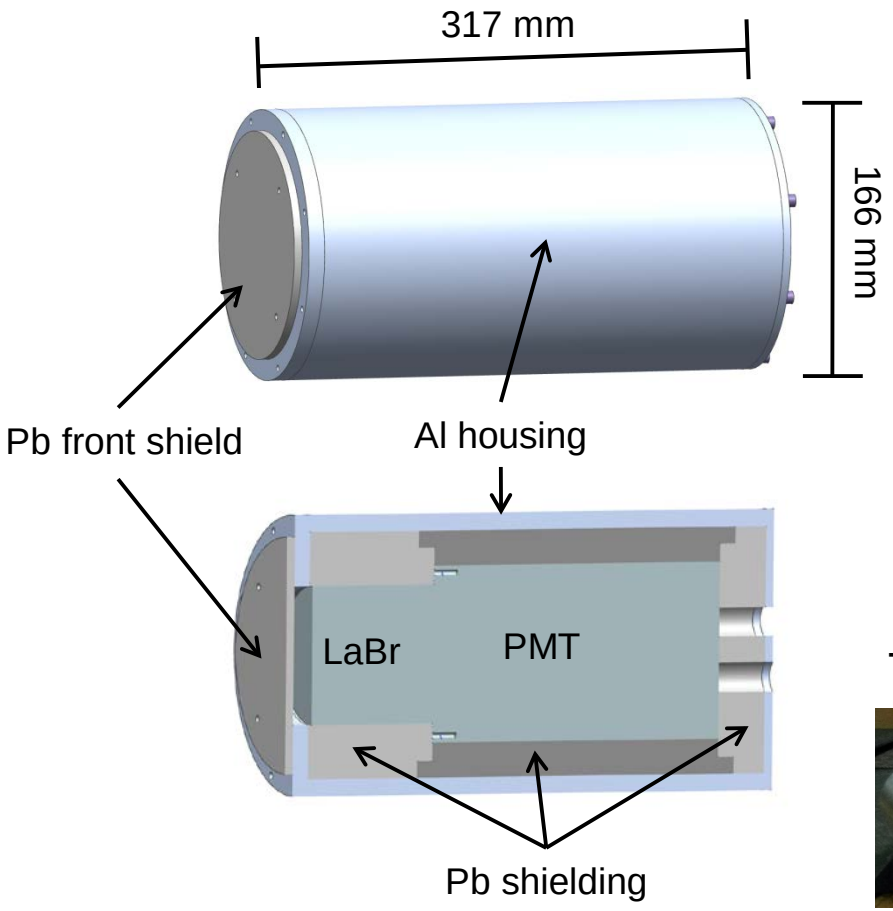
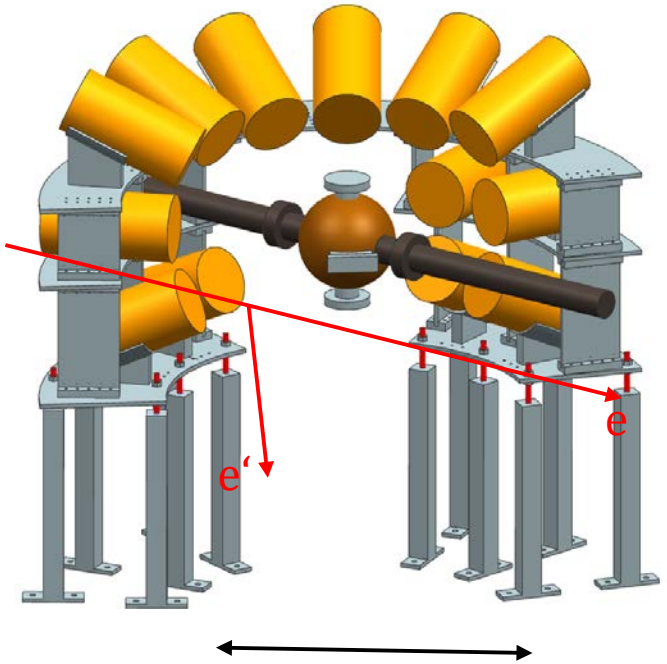
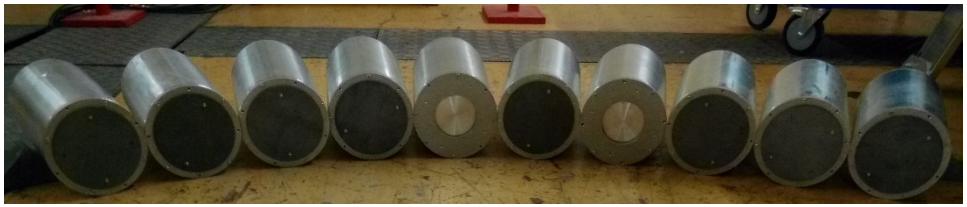
Gamma Detector Array



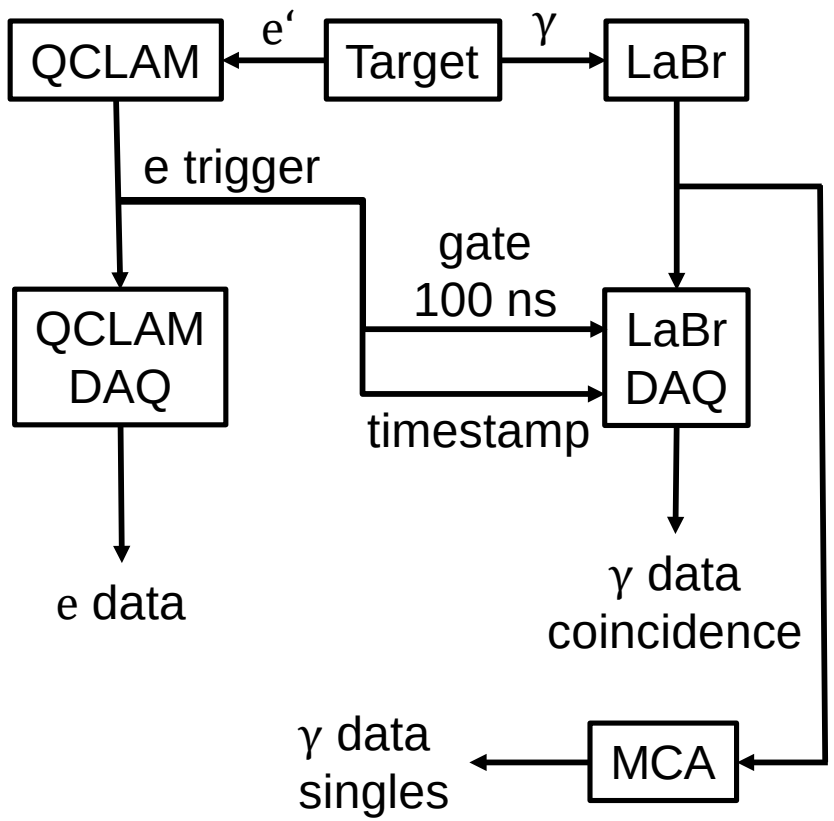


T. Klaus



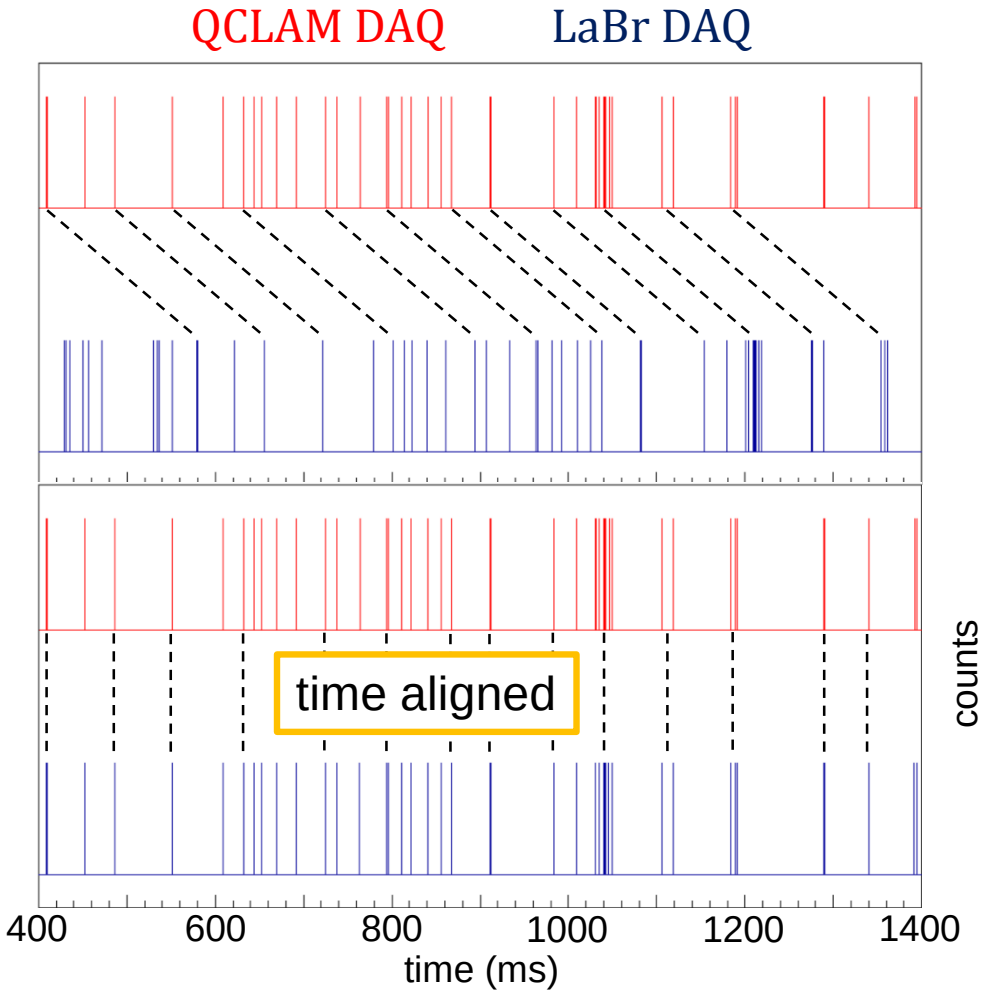
(e,e'γ) Data Acquisition

- 2 separate DAQs, MBS based
- QCLAM DAQ: M. Singer (→**B02**)
- Simultaneous acquisition of singles and coincidence data
- Electron trigger opens gate
- Full pulse shape analysis possible
- Electron trigger generates timestamps in LaBr DAQ
- Coincidence matching by mapping trigger patterns



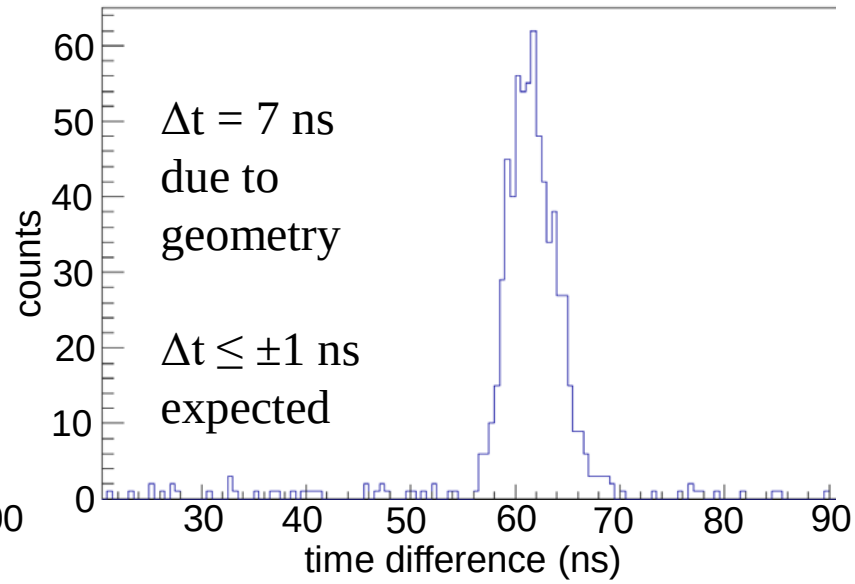
G. Steinhilber

Data Analysis

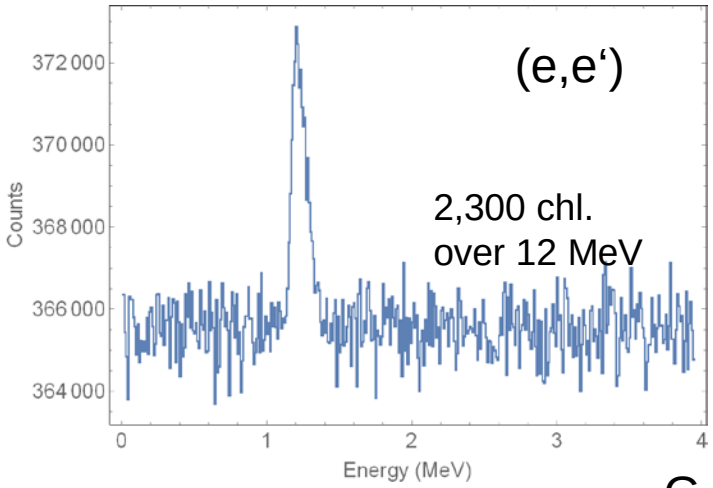


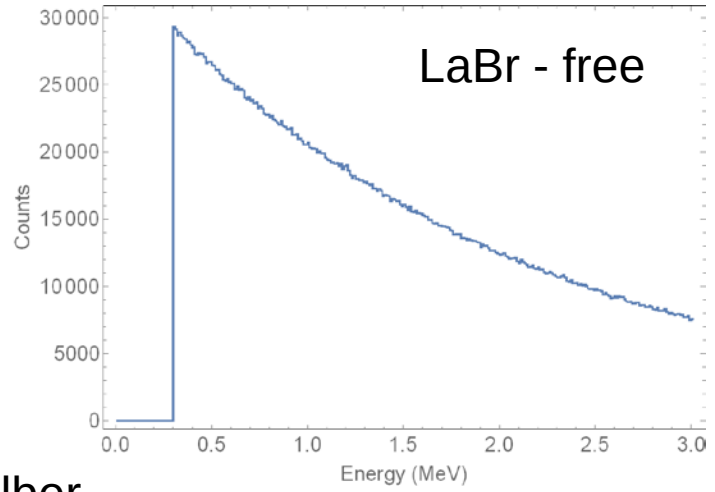
- Successfully merged Q-CLAM and LaBr data
- Measured coincidence events using cosmic showers

G. Steinhilber



Simulation of (e,e‘γ) Performance





G. Steinhilber

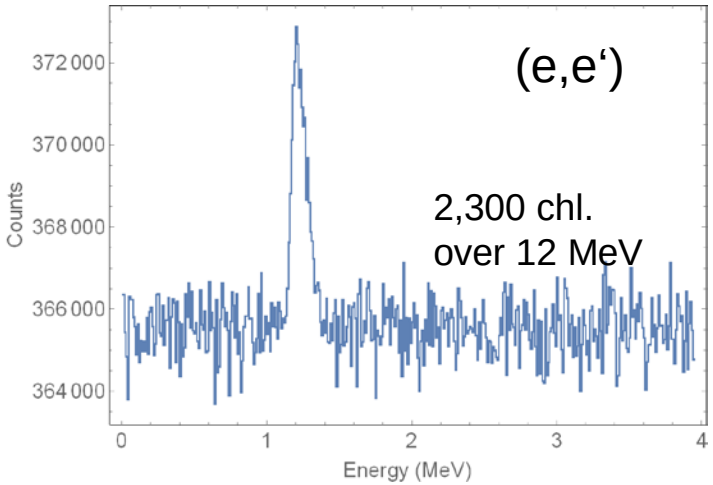
Q-CLAM typical parameters

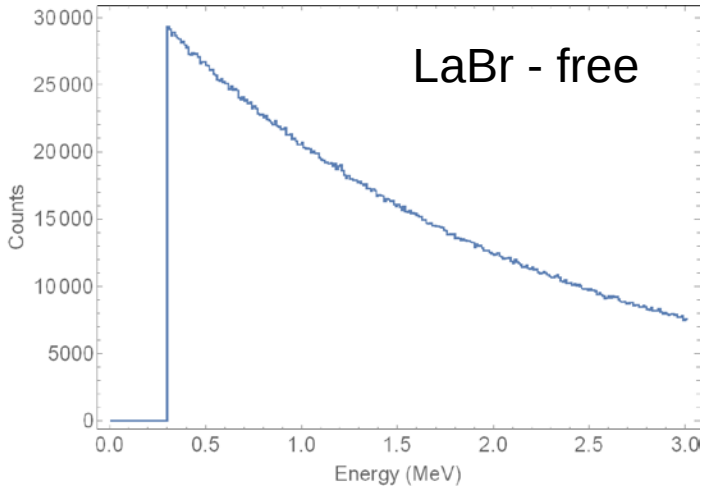
E_e (MeV)	60
E_x (MeV)	1.2
Count rate:	5 kHz
Peak count rate	1 Hz
Measuring time	24 h
Peak counts	80,000

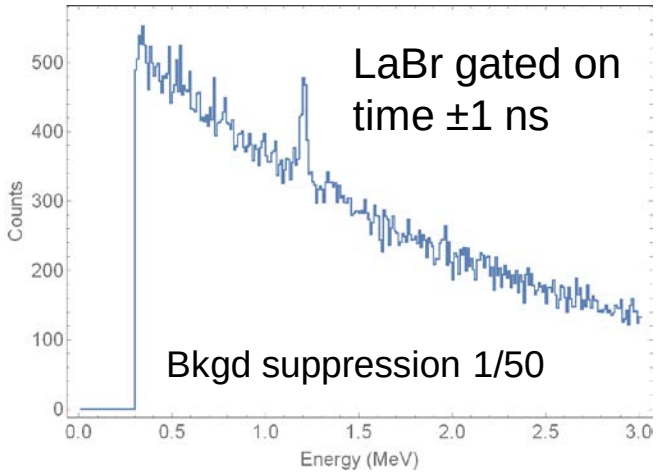
LaBr typical parameters

Count rate:	100 kHz
Energy resolution	3.5%
Time resolution	±1 ns
Abs. efficiency	0.6% per det.
Coin. Count rate	6 10^{-3} Hz
Coinc. Counts	600 / d

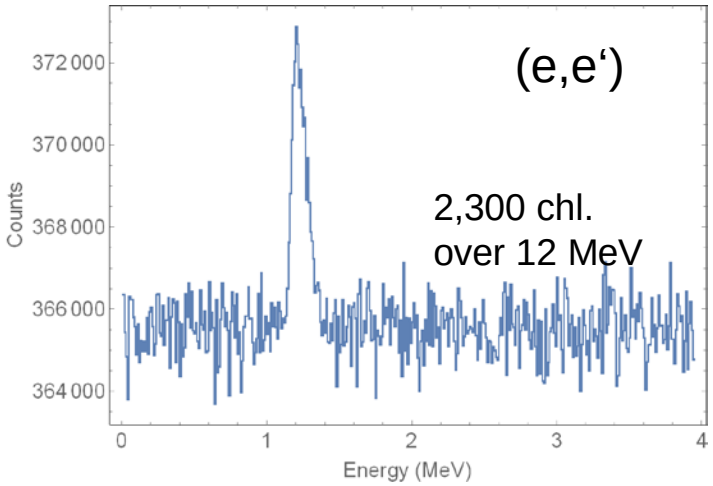
Simulation of (e,e‘γ) Performance

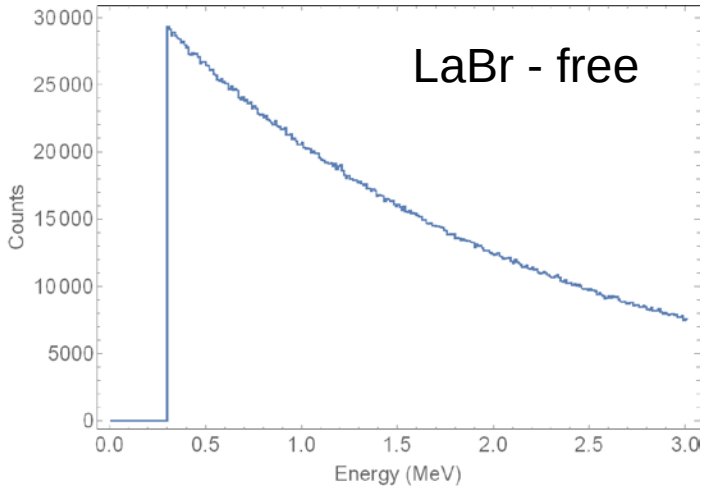


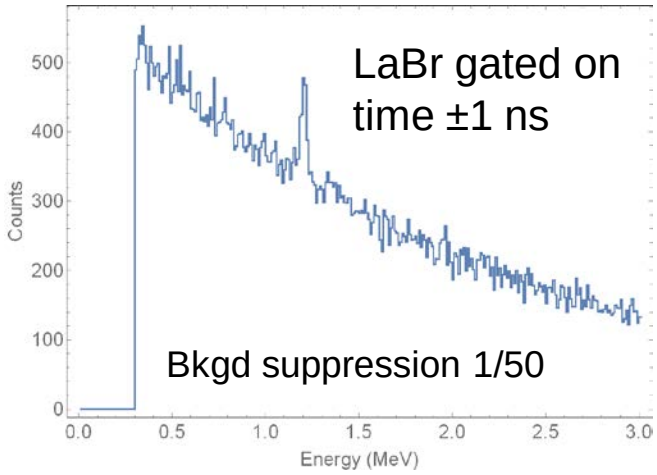


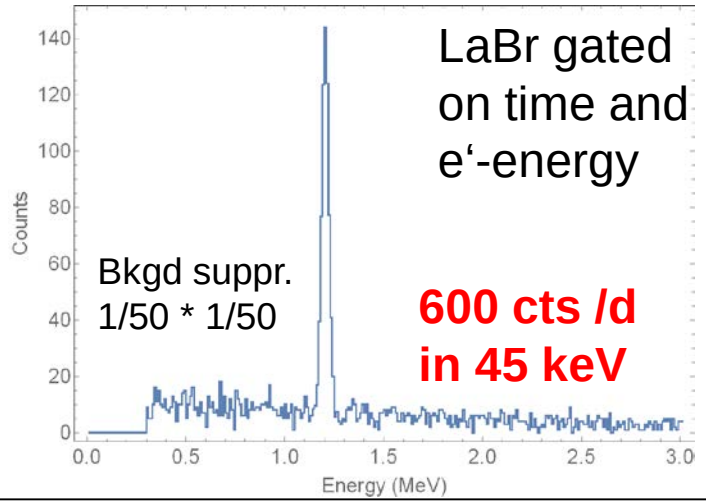


Simulation of (e,e‘γ) Performance

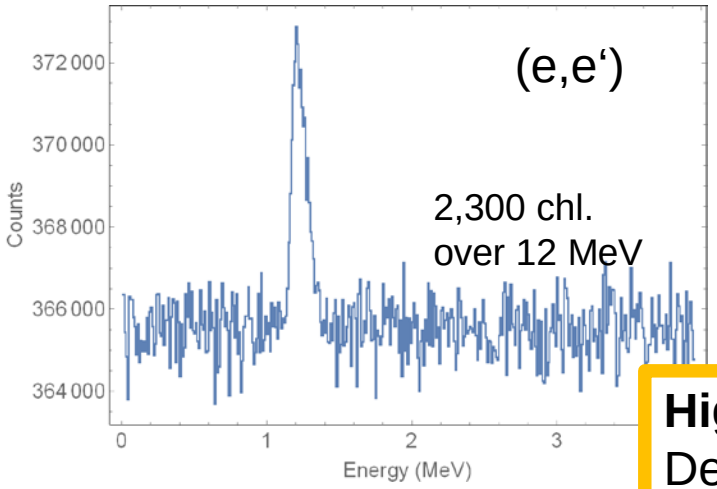


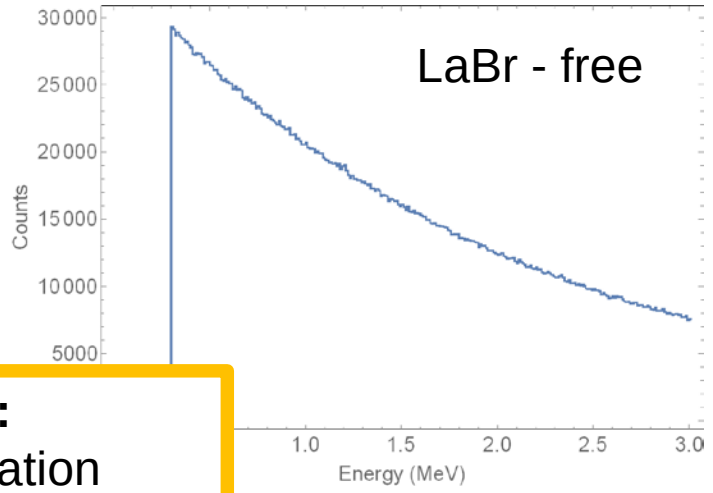




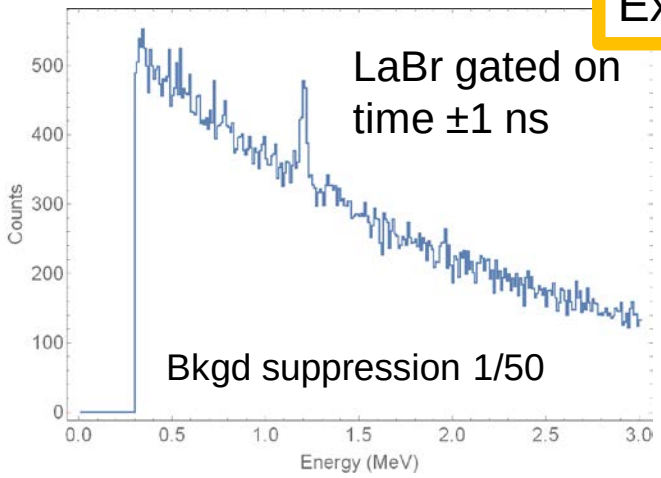


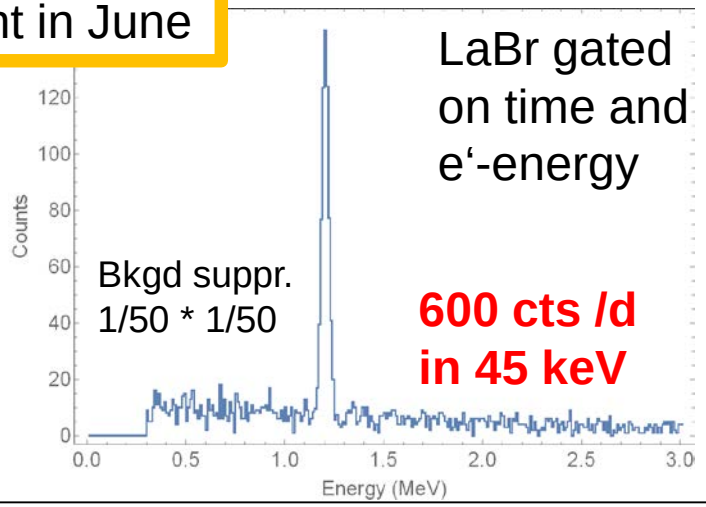
Simulation of (e,e‘γ) Performance





Highlight:
Demonstration
Experiment in June





Summary and Outlook

TECHNISCHE UNIVERSITÄT DARMSTADT

Summary

- $(e,e'\gamma)$ coincidence-spectroscopy setup established
- DAQ for coincidence measurement developed
- Setup tested with cosmic showers

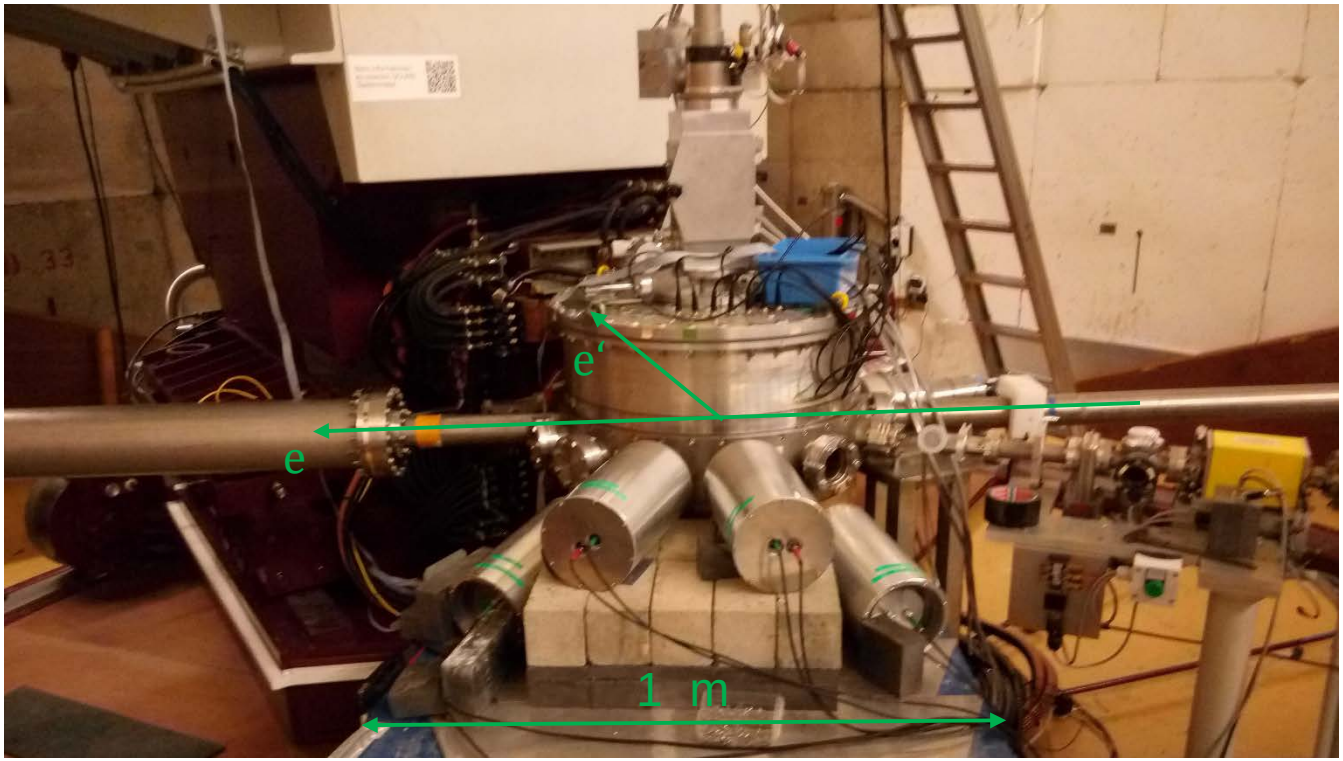
Outlook

- Performance demonstration foreseen for June
- Pulsed electron beam → further background suppression for more challenging experiments

L. Stobbe, DPG - AKBP 15.12

SFB 1245

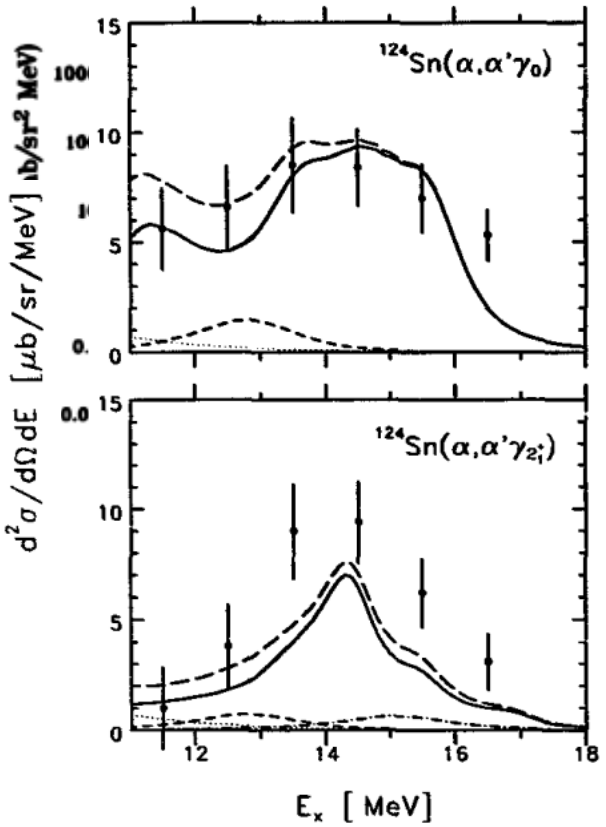
Thank you!



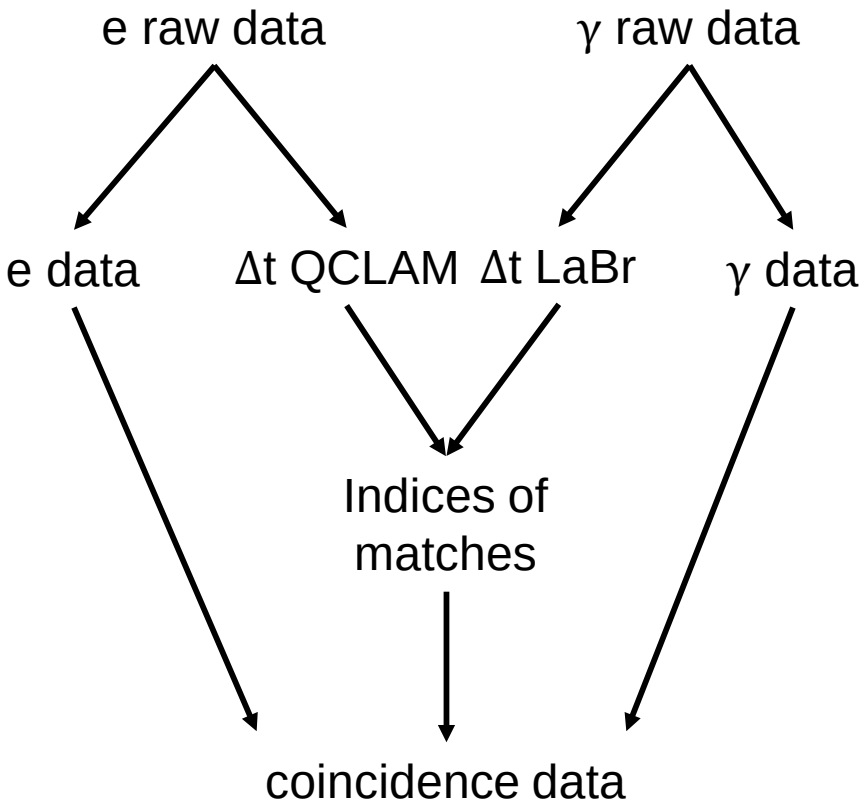
- 4 LaBr detectors at the QCLAM spectrometer
- Successful demonstration of mapping e to γ data

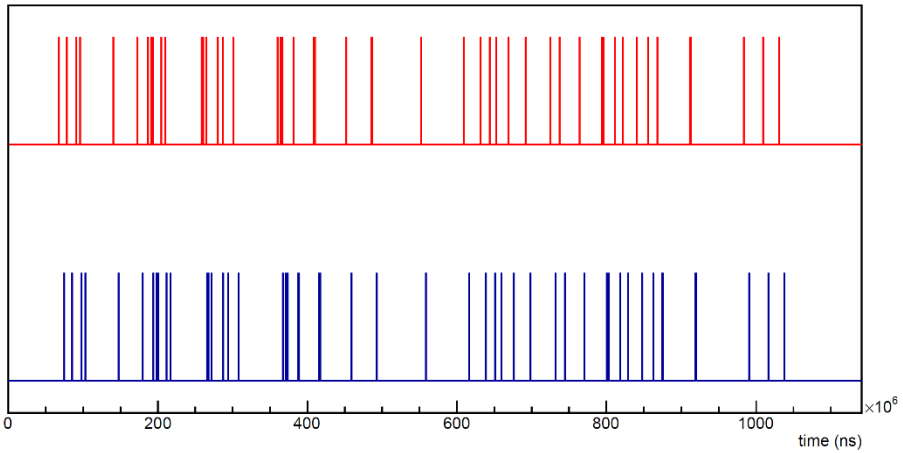
Decay of Resonances

- GDR γ-decay branching: ≈ 1 %
  J. R. Beene et al., Phys Rev. C (1990)
- Relative branching from GDR to 2_1^+ almost as strong as to ground state
- GDR built on 2_1^+
  $\Gamma_{\gamma 2_1^+}\left(E_{1^-\nu} - E_{2_1^+}\right) \sim \left|R_1(2^+1)\sum_i P_{1^-i}^{2_1^+}\langle 2_1^+||E1||[1_i^- \otimes 2_1^+]_{1^-}\rangle\right|$
  V. Yu. Ponomarev et al., Nucl. Phys. (1992)
- Investigate γ-decay of GDR in ^{112,124}Sn

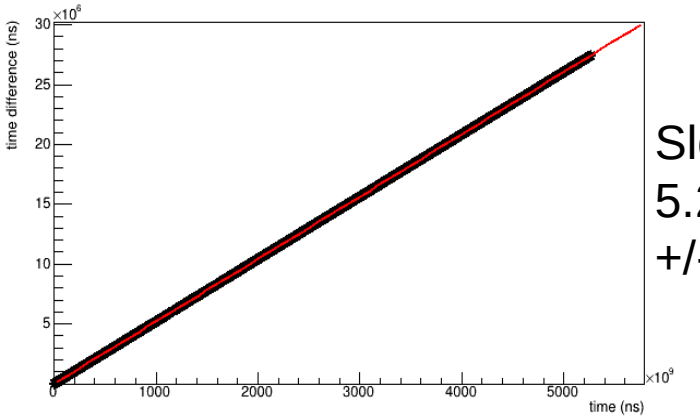


Requirements: Data Acquisition
Data Analysis





QCLAM-DAQ LaBr-DAQ



Slope:
5.2 µs/s
+/- 3.9 ps/s