Particle detectors for low-energy Coulomb excitation

RIB vs stable beams requirements

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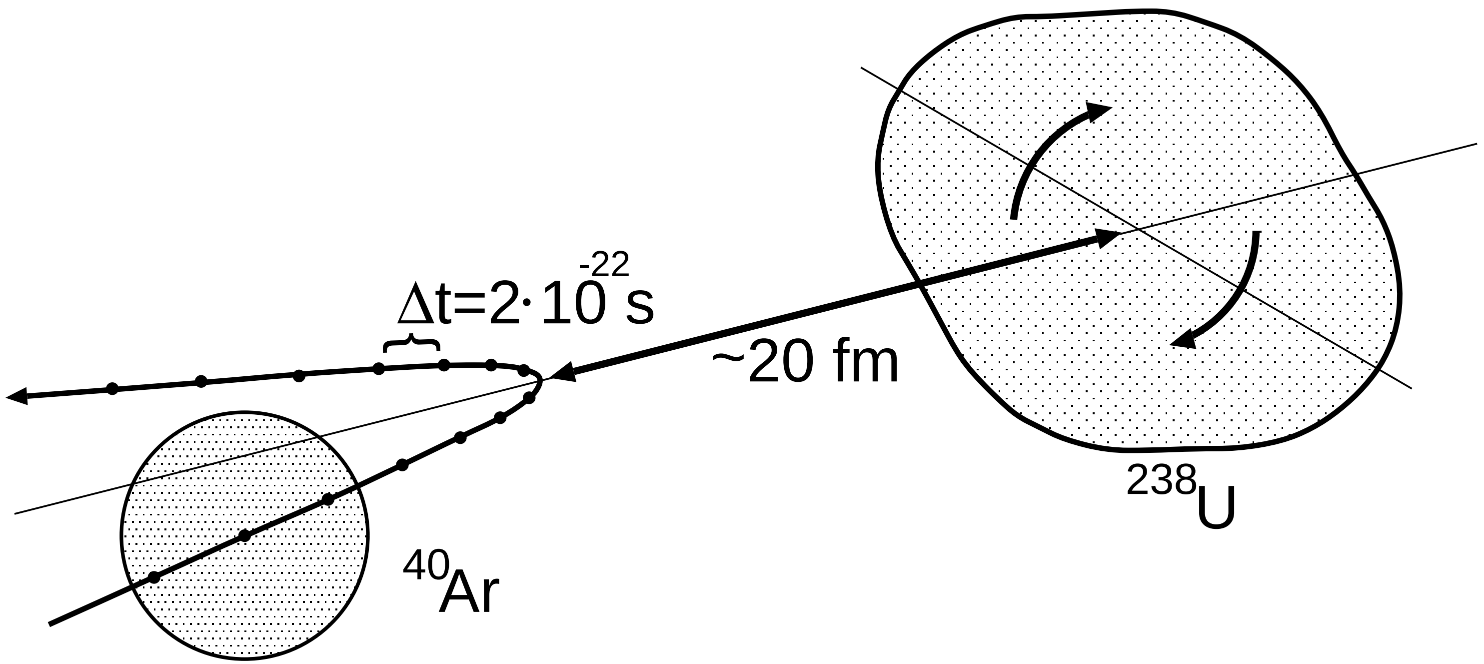
- Coulomb excitation: Why do we need particle detectors?
- Coulex detectors:
  - Stable beams: detectors in backward angles
  - Stable and exotic beams: Detectors in forward angles – identification problems
- What next?
  - Future challenges
  - What else has to be measured when we have our Coulex data?

Why do we like Coulomb excitation?

- it's a very precise tool to measure the collectivity of nuclear excitations and in particular nuclear shapes
- shape = fundamental property of a nucleus, "condensed" information about its structure
- excitation mechanism purely electromagnetic, the only nuclear properties involved: matrix elements of electromagnetic multipole operators
- nuclear structure information extracted in a model-independent way



Why do we like Coulomb excitation?

- studies no longer limited to stable or long-lived nuclei
- beam energies at exotic beam facilities perfect for Coulomb excitation (2-5 MeV/A)
- high cross sections (excitation of 2_1^+: barns)
- practical at the neutron-rich side

- direct measurement of nuclear shape (quadrupole moment including sign) – ideal tool to study shape coexistence
- B(E2) as a measure of collectivity - studies around magic numbers
- easy way to access non-yrast states and study their properties

Basic facts about Coulex

- Due to the purely electromagnetic interaction the nucleus undergoes a transition from state $|i\rangle$ to $|f\rangle$.

- Then it decays to the lower state, emitting a γ-ray (or a conversion electron).

- The matrix elements $\langle f||M(E2)||i\rangle$ describe the excitation and decay pattern $\rightarrow$ they are directly connected with γ-ray intensities observed in the experiment.

- In the intrinsic frame of the nucleus they are related to the deformation parameters.

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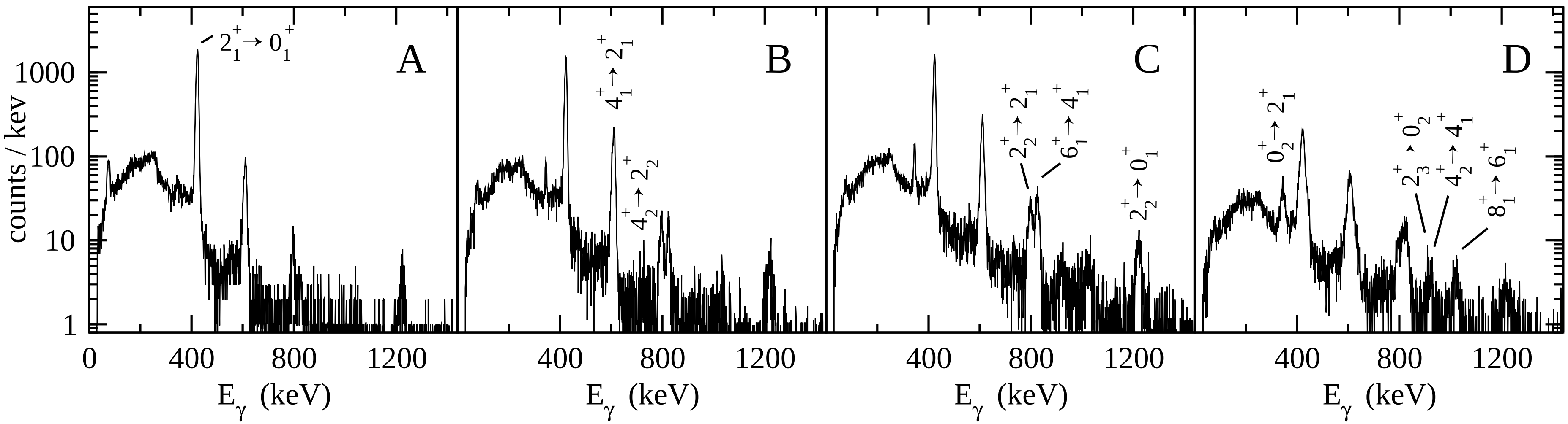
Why are particle detectors useful in Coulex experiments?

- to select Coulomb excitation events (intermediate-energy Coulex, exotic beam experiments, experiments with oxide targets...)
- to describe the excitation process $\rightarrow$ information on θ scattering angle needed
- to perform a Doppler correction of gamma rays $\rightarrow$ information on θ and ϕ necessary
- to measure particle-gamma angular correlations $\rightarrow$ information on ϕ generally more useful

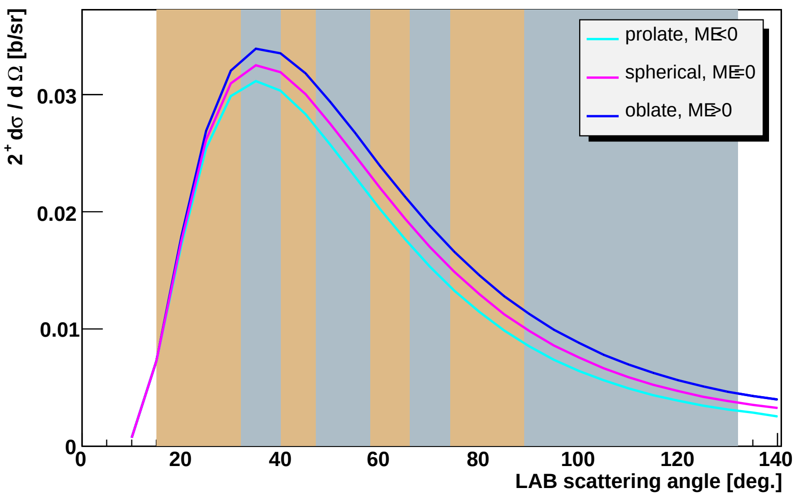


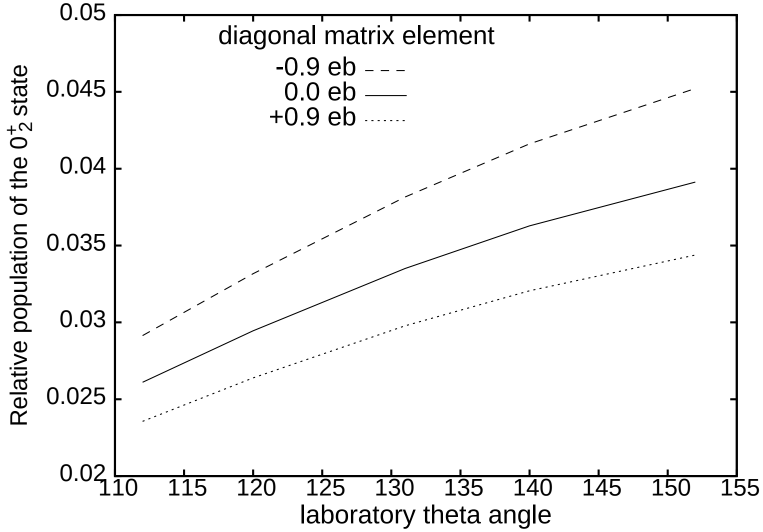
Reorientation effect

- influence of the quadrupole moment of the excited state on its excitation cross-section

- dependence on scattering angle and beam energy

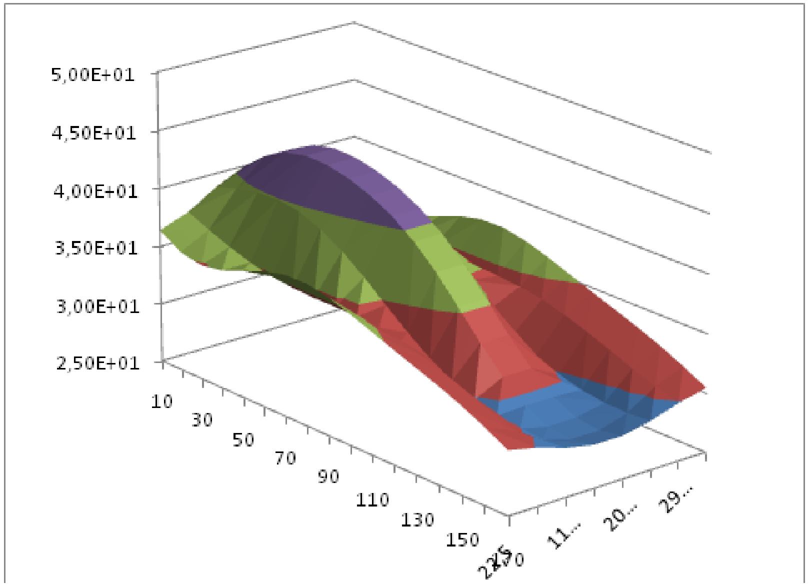
- BE CAREFUL – influence of double-step excitation of higher states may have the same effect!

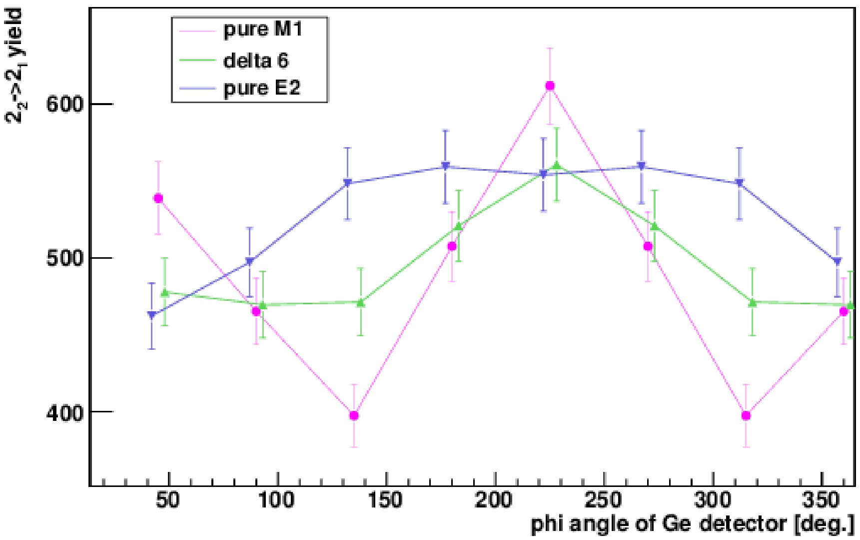




Gamma-particle angular correlations

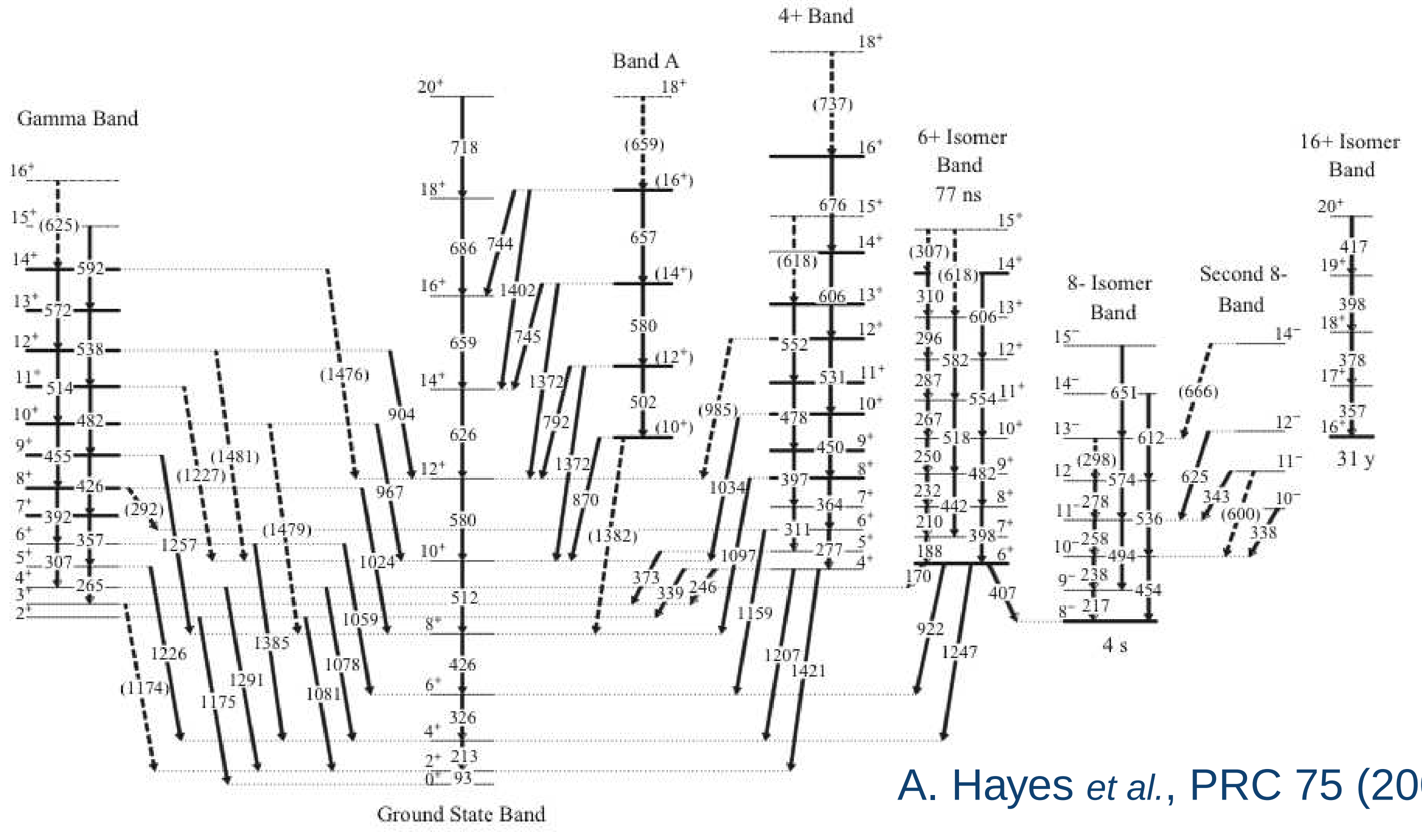
- feasible at several thousands of counts in a given gamma line
- determination of E2/M1 mixing ratios
- determination of spin of a decaying level
- distribution in phi usually more conclusive than in theta





Stable beam experiments

- usually multi-step excitation and complicated level schemes, search for subtle effects
- beam intensities of the order of pnA $\rightarrow 10^{10}$pps: particle detectors usually at backward angles
- lifetimes of several states known: no need for other kind of normalisation
- statistics enough for particle-gamma angular correlations



^{178}Hf

A. Hayes *et al.*, PRC 75 (2007) 034308

Exotic beam experiments

- usually one- or two-step excitation; level schemes not well known on the neutron-rich side

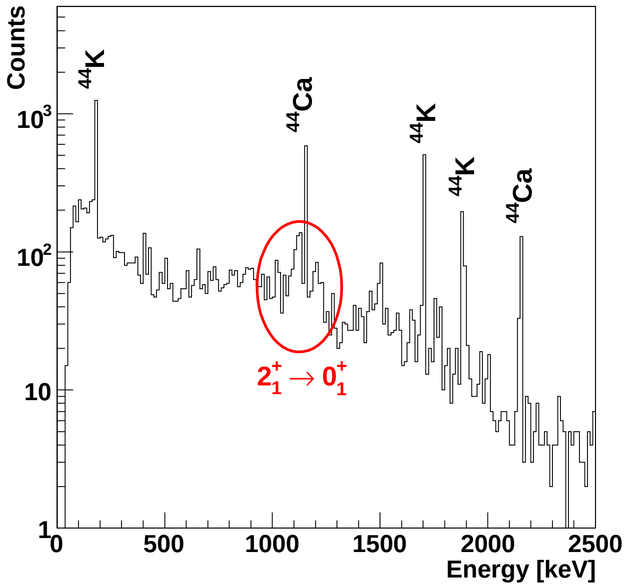
- beam intensities rather low: particle detectors at forward angles to maximise the statistics

- normalisation to target excitation or Rutherford scattering needed

- low statistics, sometimes only one gamma line observed

- differential measurements at the limits of feasibility

- high background from β decay
$\longrightarrow$ experiments without particle detection impossible

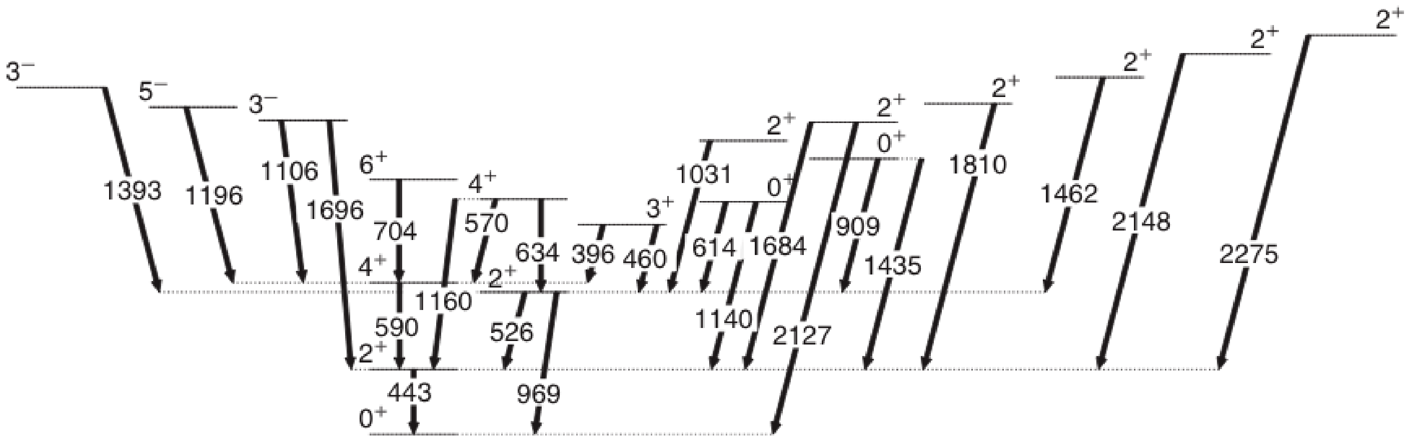


Simplest Coulex detector: no detector at all

Doppler correction impossible; how can we manage?

- traditional "thick target" measurements
  $\longrightarrow$ lifetimes should be long compared to stopping time

- strongly assymetric inverse kinematics, everything goes forward
  $\longrightarrow$ favours one-step excitation - suitable for example to search for mixed symmetry 2^+ states

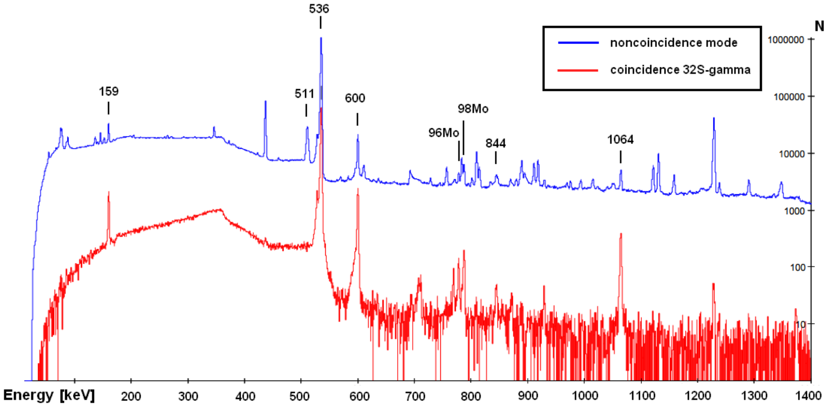


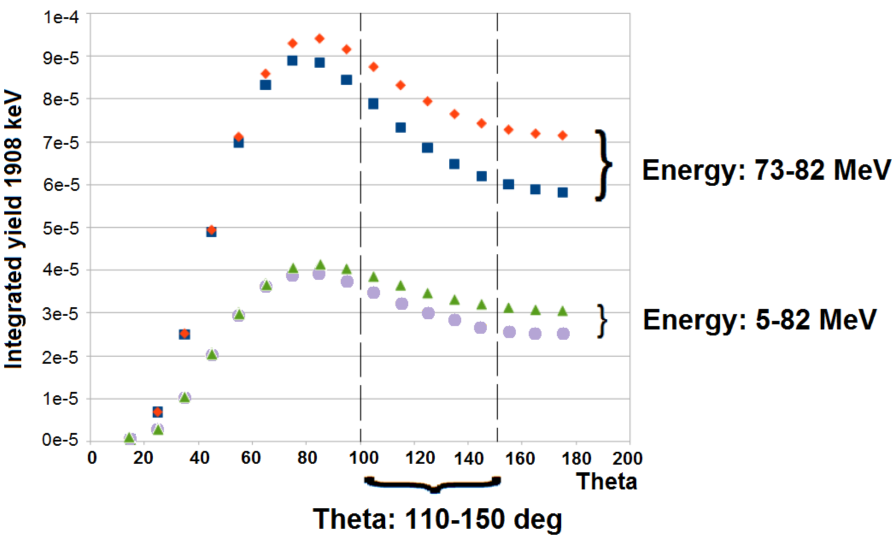
^{128}Xe on ^{12}C

L. Coquard *et al.*, PRC 80 (2009) 061304

Simplest Coulex detector: no detector at all

- possibility of collecting gamma singles in a particle-γ coincidence measurement:
  - independent data set (different ranges of incident energy and scattering angles)
  - can help to disentangle various excitation patterns!

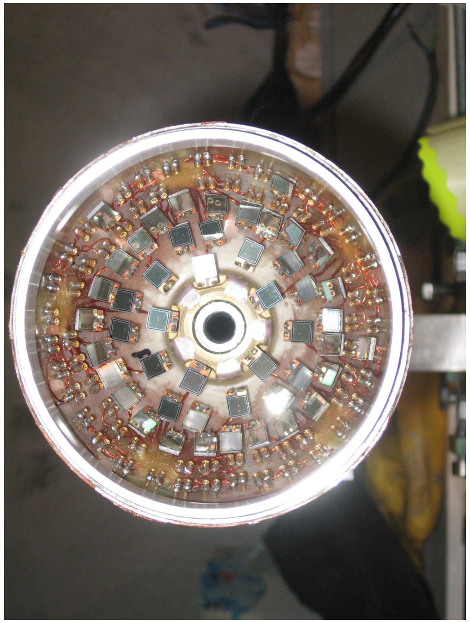


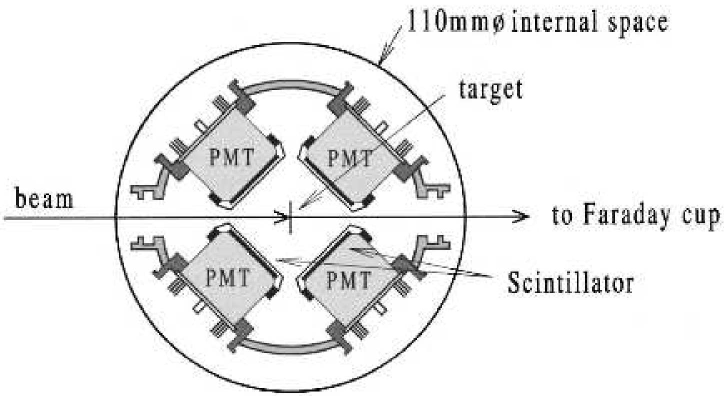


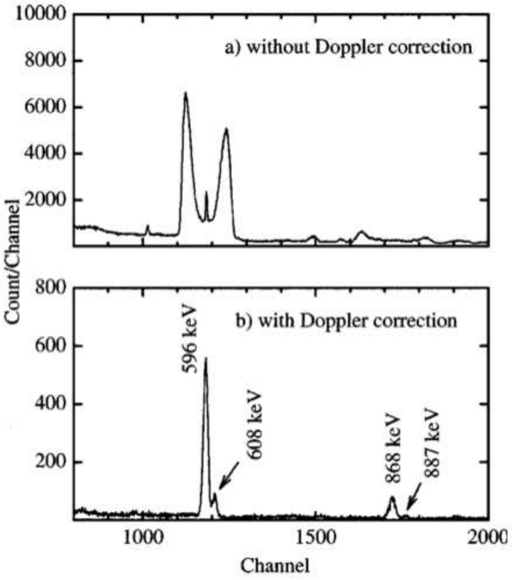
^{32}S on ^{100}Mo
K. Hadyńska-Klęk *et al.*, to be published

"Standard" stable beam Coulex: detectors at backward angles

- only scattered beam particles detected – in principle no need to know their energy
  - (although it may help – makes possible to make cuts on incident energy)
- very compact geometry possible (chambers of 5 cm radius)
- detectors used: Si (segmented/PIN diodes), plastic, solar cells, MCP,...







Munich Chamber, HIL Warsaw

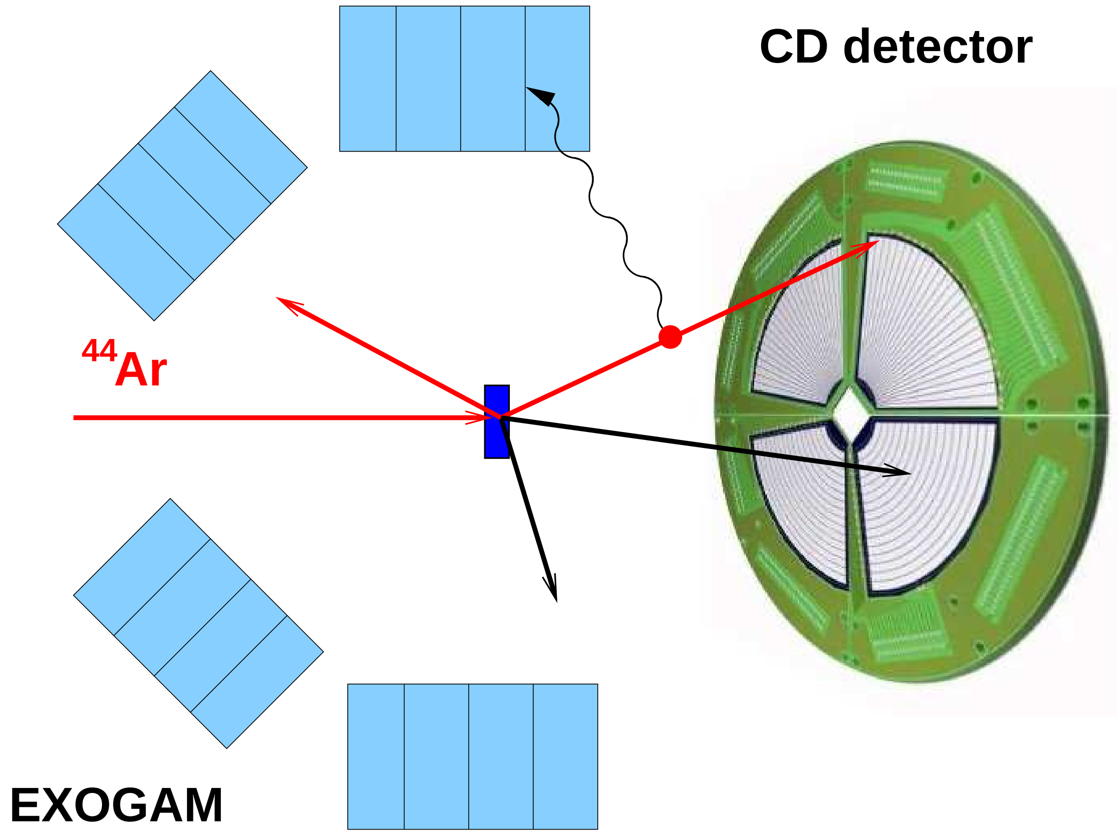
K. Wrzosek *et al.*, Acta Phys. Pol. B39 (2008) 513

LUNA, JAEA Tokai

Y. Toh *et al.*, Rev. Sci. Inst. 73 (2002)

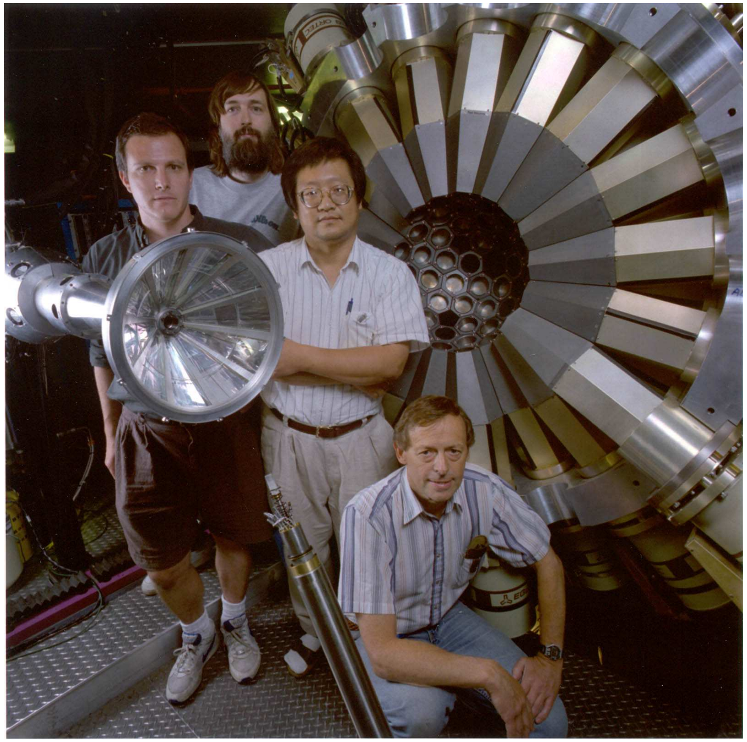
"Standard" exotic beam Coulex: detectors at forward angles

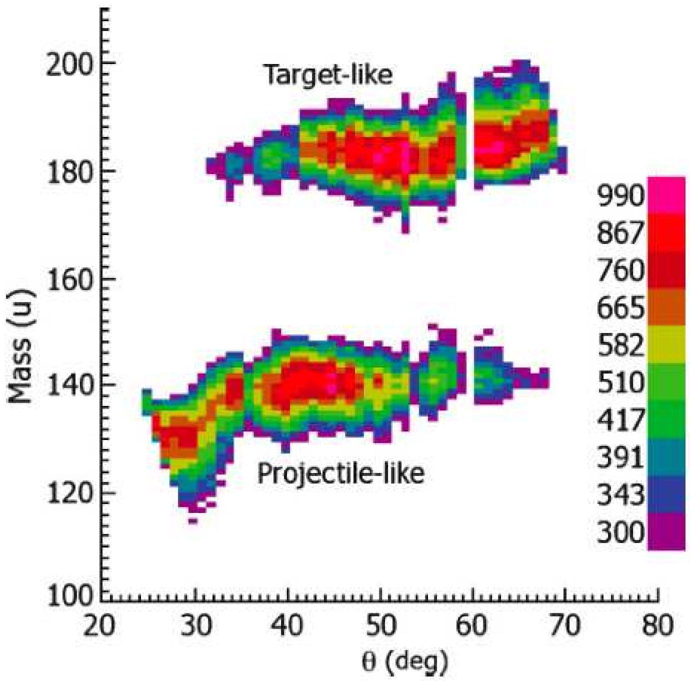
- simultaneous detection of scattered projectiles and recoils
- unambiguous identification necessary for excitation process description & Doppler correction
- detectors used: PPAC (stable beams), segmented Si / CsI(Tl) (exotic beams)



Identification ejectile-recoil: time

- CHICO: 4 π PPAC array designed for GAMMASPHERE
- chamber diameter 36 cm (distance target-detector 15 cm)
- timing resolution 500 ps
- for ^{136}Xe + ^{178}Hf Coulex: 10 ns TOF difference, ejectile and recoil well resolved



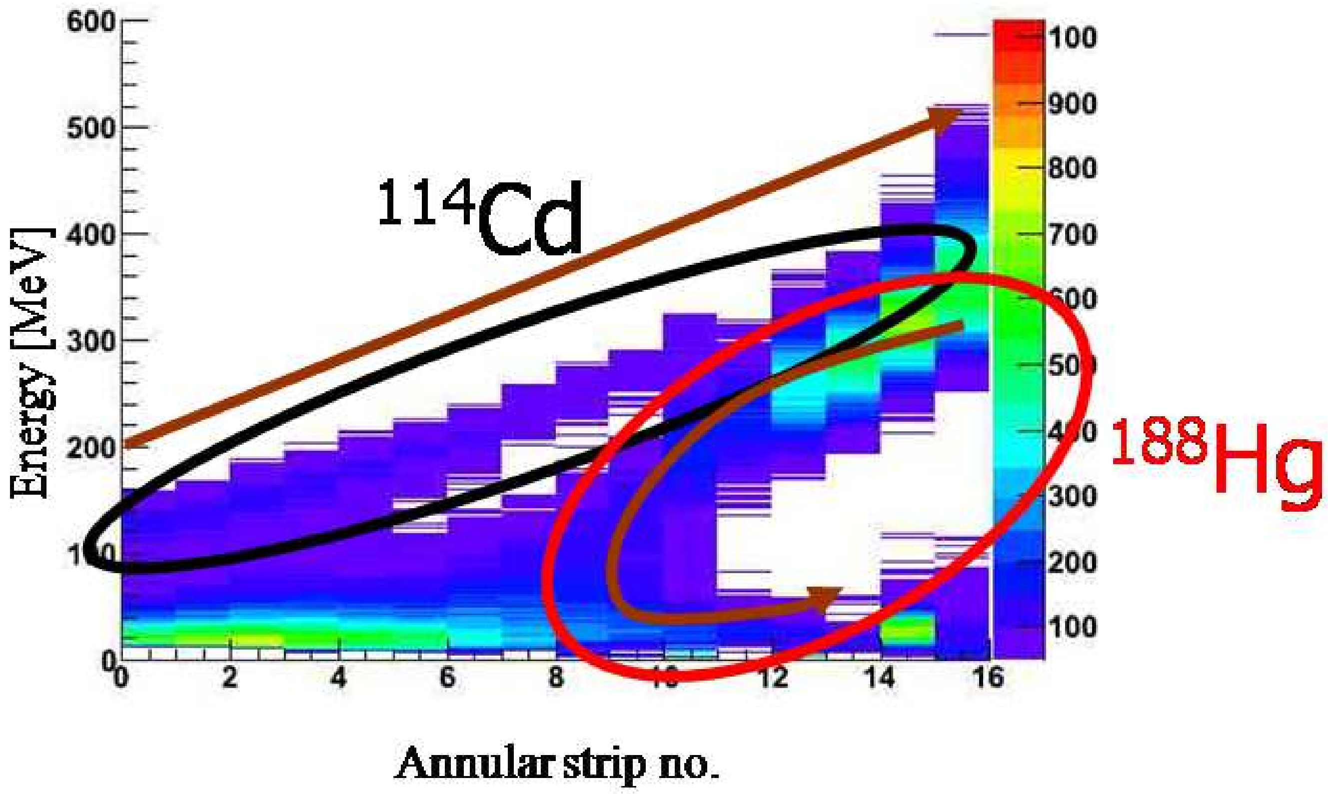


A. Hayes *et al.*, PRC 75 (2007) 034308

Identification ejectile-recoil: energy

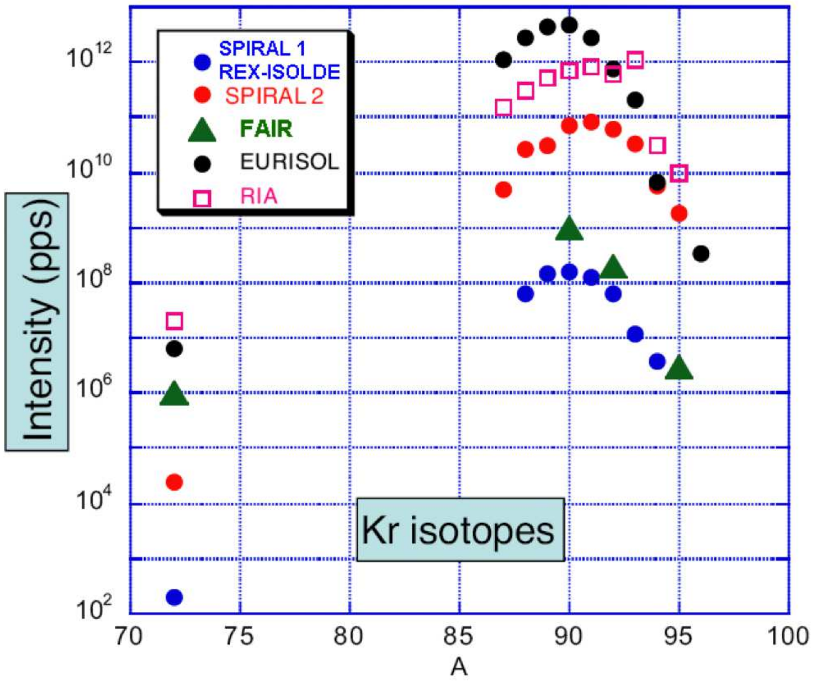
• for Si detectors and targets of 1-2 mg/cm^2: ejectile and recoil should differ in mass by roughly a factor of two

• this limits observed excitation for mass > 100 (heavy targets like Pt or Pb cannot be used)



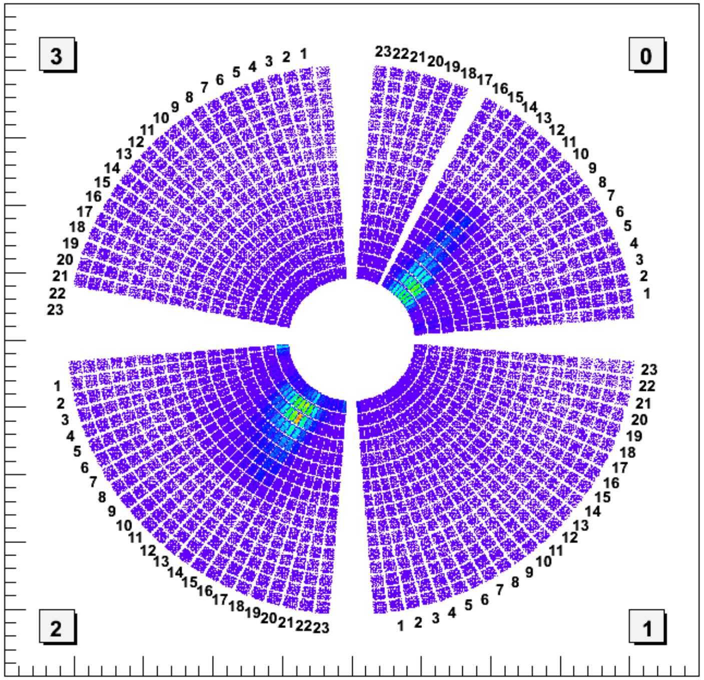
Exotic beam experiments: future

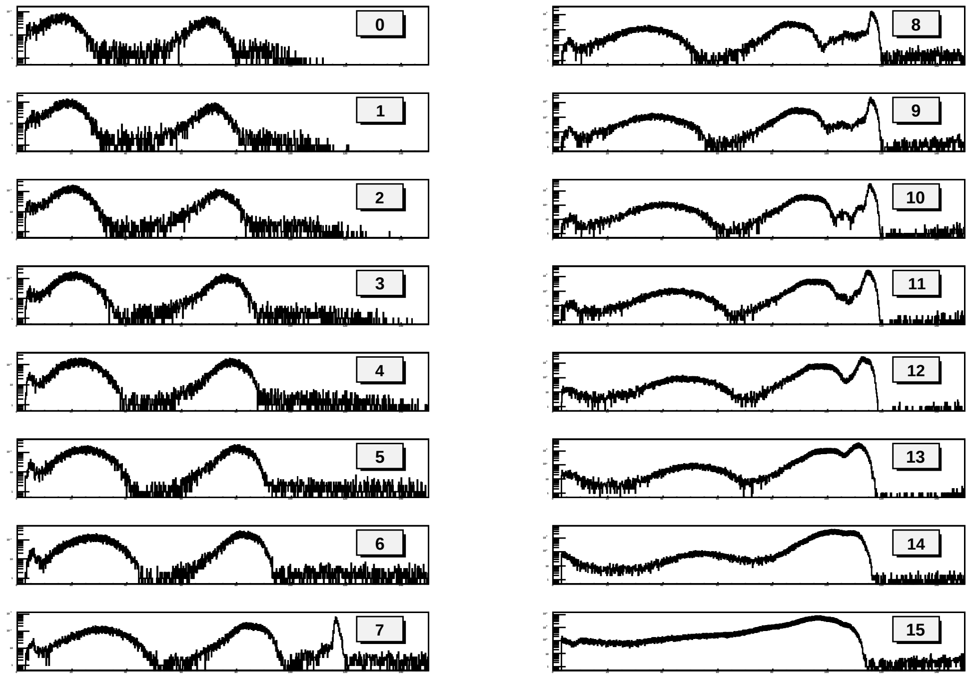
- increase in RIB intensities
- multi-step excitation experiments will become common
- Coulex one of the most important methods to measure transition probabilities on the neutron-rich side
- need for novel particle detectors



Si detectors for high-intensity RIB Coulex?

Coulomb excitation of ^{44}Ar





Direct beam of intensity 10^3 pps hitting 5-10% of detector area

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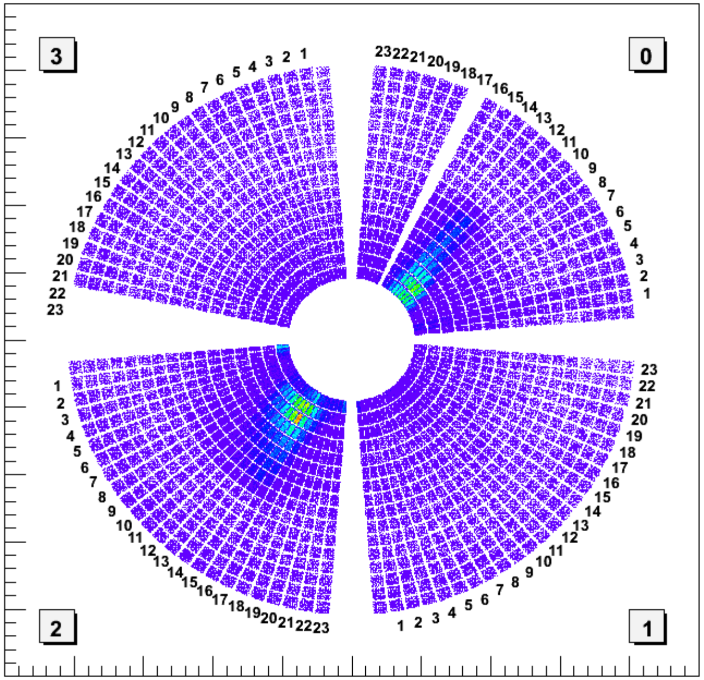
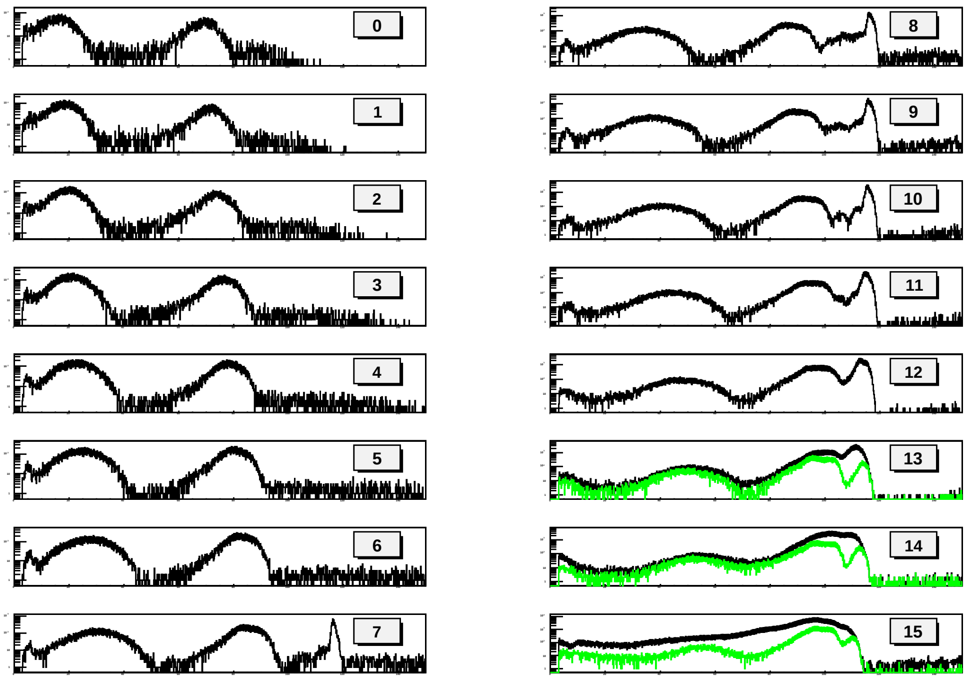




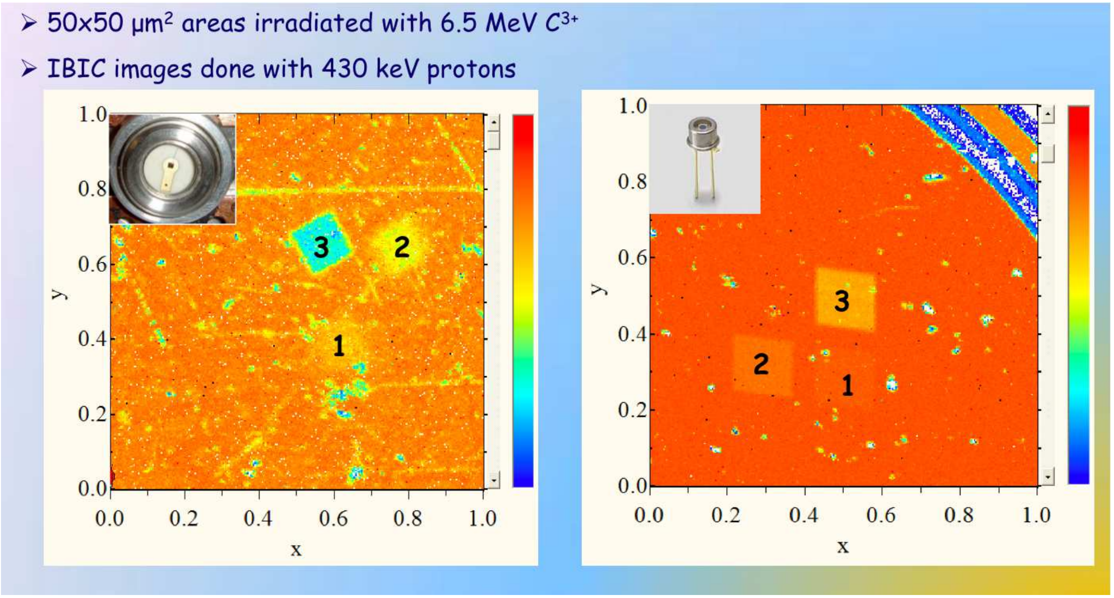
Direct beam of intensity 10^3 pps hitting 5-10% of detector area

Rate equivalent to Rutherford scattering of 10^8 pps beam at $15^\circ < \theta < 25^\circ$

Diamond CVD detectors

- promising detector material for harsh environment: used for beam monitoring in high-energy physics (CERN, HADES...)
- high E_g $\rightarrow$ negligible leakage current at the room temperature
- low dielectric constant $\rightarrow$ low capacitance $\rightarrow$ low noise
- high carrier mobility $\rightarrow$ fast signal collection $\rightarrow$ excellent timing properties

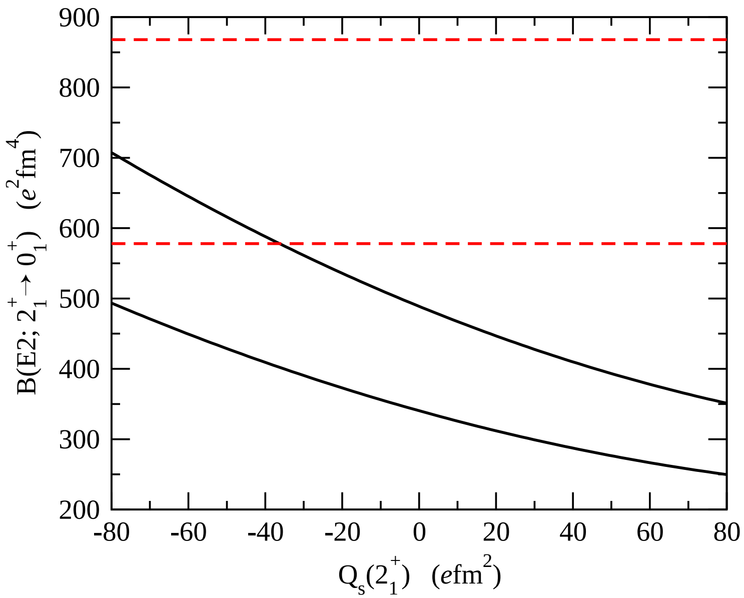
- but... contradictory infomation on radiation hardness of SC diamond detectors



I. Zamboni *et al.*, submitted to Diamond and Related Materials

Additional measurements needed for Coulex data analysis...

- lifetime measurements
  - necessary for integral cross-section measurements



A.M. Hurst *et al.*,

Phys. Rev. Lett. 98, 072501 (2007)

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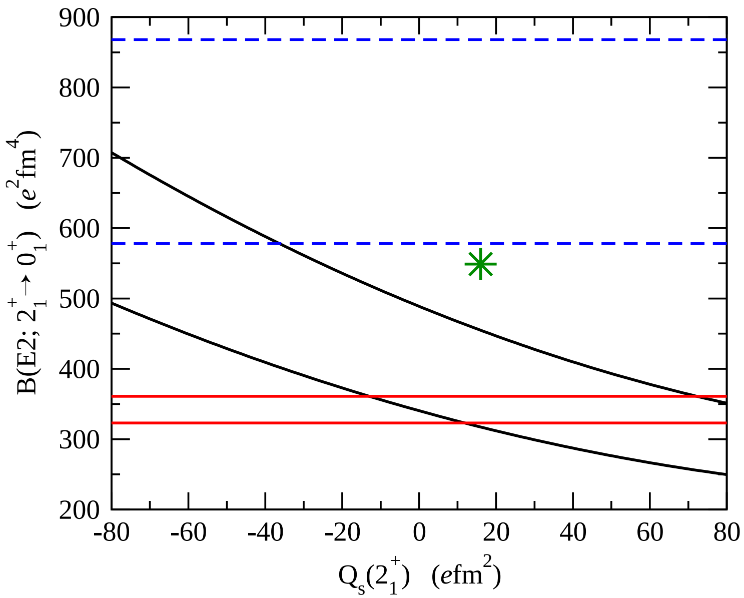

J. Ljungvall *et al.*,
Phys. Rev. Lett. 100, 102502 (2008)

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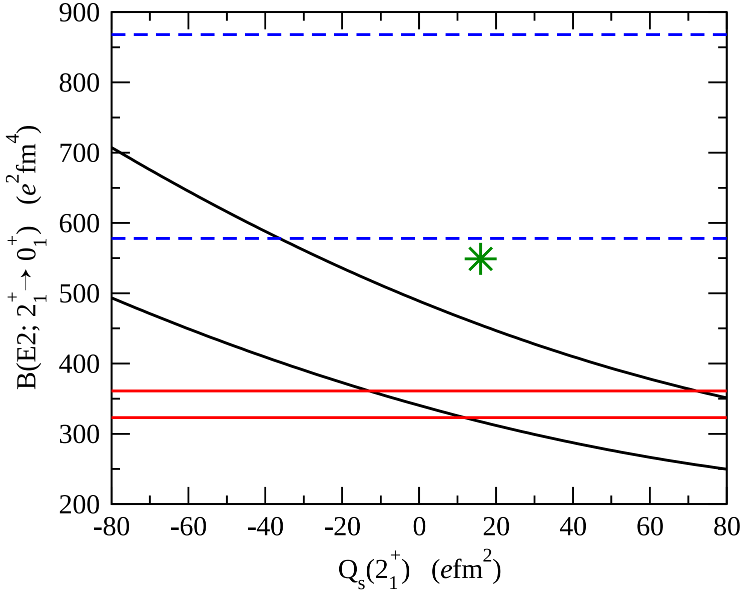


J. Ljungvall *et al.*,
Phys. Rev. Lett. 100, 102502 (2008)

  - increase precision of quadrupole moments/intra-band matrix elements for differential measurements
- beam composition (isobaric contamination/isomeric ratio)
- beam energy
- conversion coefficients/E0 branchings

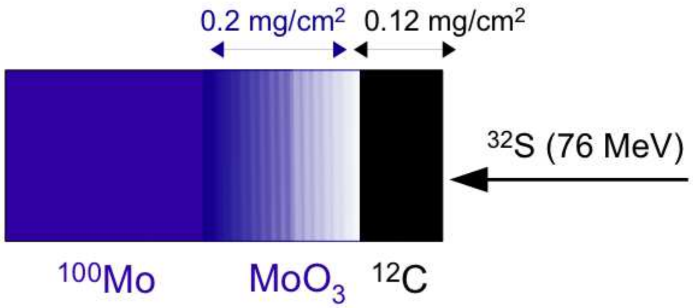
Beam purity, cocktail beams

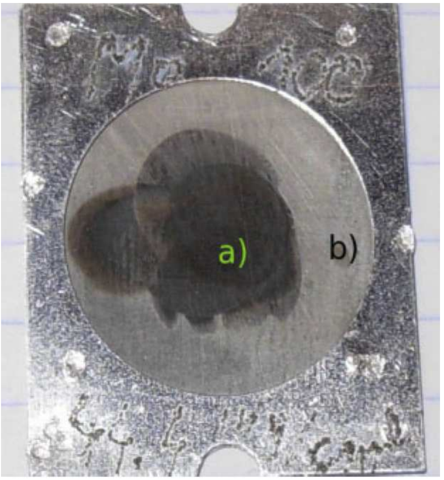
Especially for exotic nuclei, what we want to study may be a small fraction of the beam... What can we do to determine the beam composition?

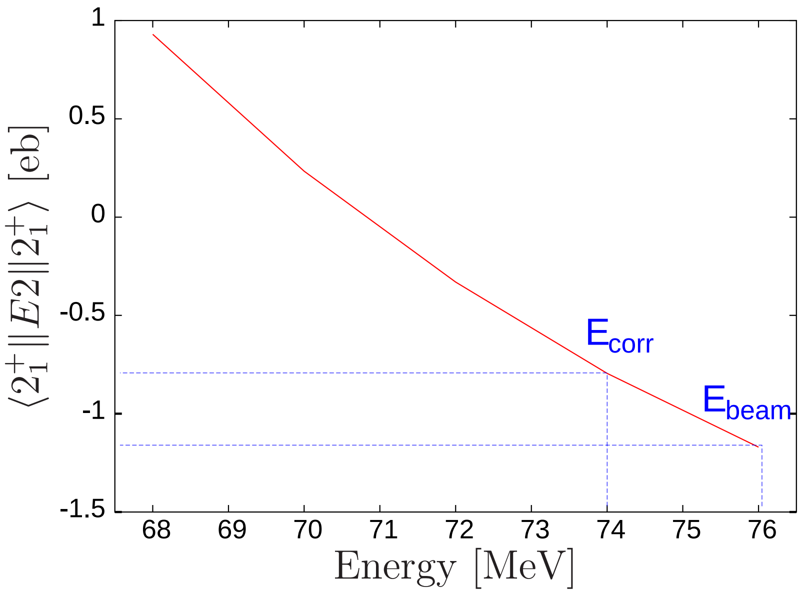
- Measure gamma-ray spectra of decay products – and what if we have stable contaminants?
- Ion chambers at the beam dump, energy measured by particle detectors – if difference in mass is big enough
- Laser ionisation with periodically blocked laser – excellent, not possible for all elements
- Mass separator for scattered ejectiles – limitation to forward scattering angles
- Brute force approach: if a dominant contamination is much heavier (e.g. Xe in Ar beam) – choosing a target giving normal kinematics for Ar, inverse for Xe and measuring in backward angles only

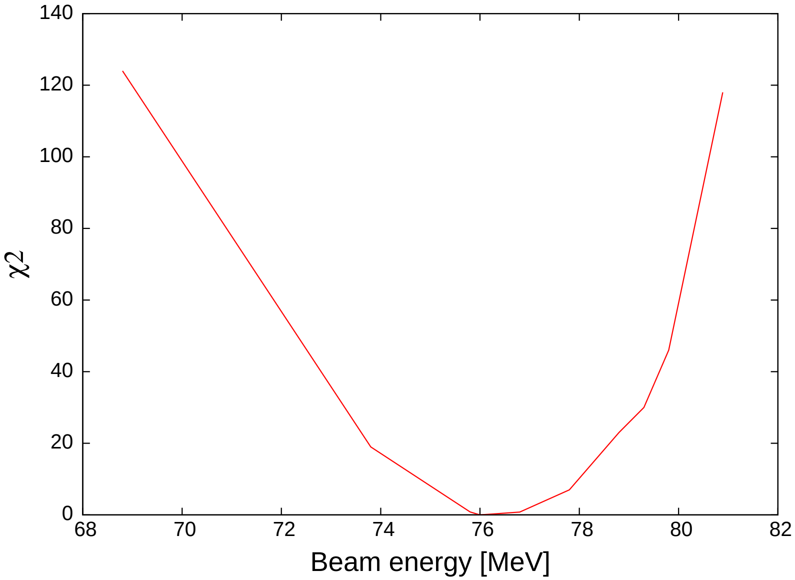
Incident energy

- Strong dependence of multi-step excitation and reorientation effect on beam energy
- Correct beam energy required!





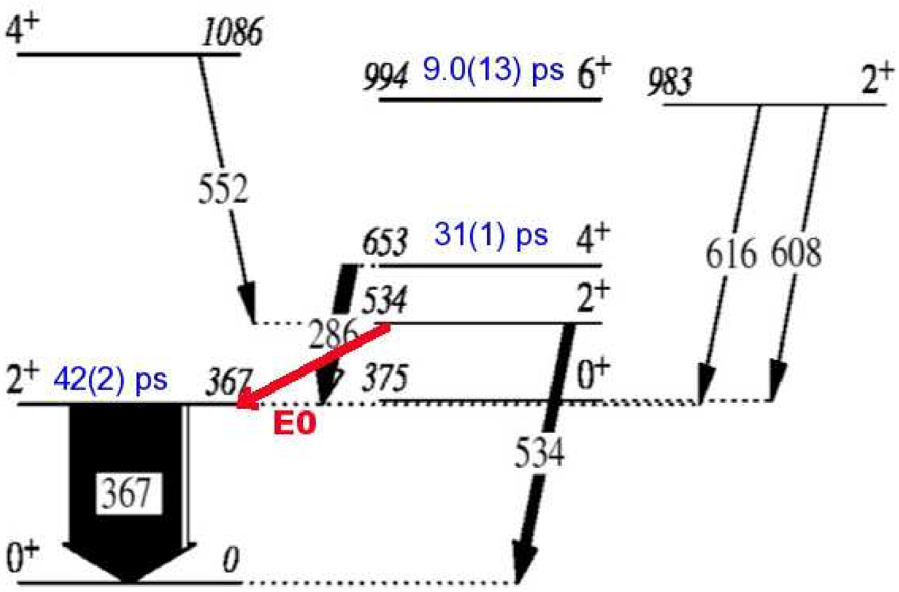




K. Wrzosek-Lipska, PhD thesis (2011)

E0 strengths

- decay branch unvisible for Ge detectors
- important for 0^+ states (^{74}Kr, ^{100}Mo,...) and heavy nuclei



$\alpha\ (2_2^+ \rightarrow 2_1^+)$ in ^{184}Hg: 23(5)

E. Rapisarda *et al.*, to be published

- electron spectroscopy measurements for strongly converted transitions?

Summary

- low-energy Coulomb excitation has a long tradition and a great future
- high intensity RIBs bring both opportunities and challenges
- progress in gamma-ray detection should be accompanied by development of new particle detectors for Coulex