PH3: LECTURE 3

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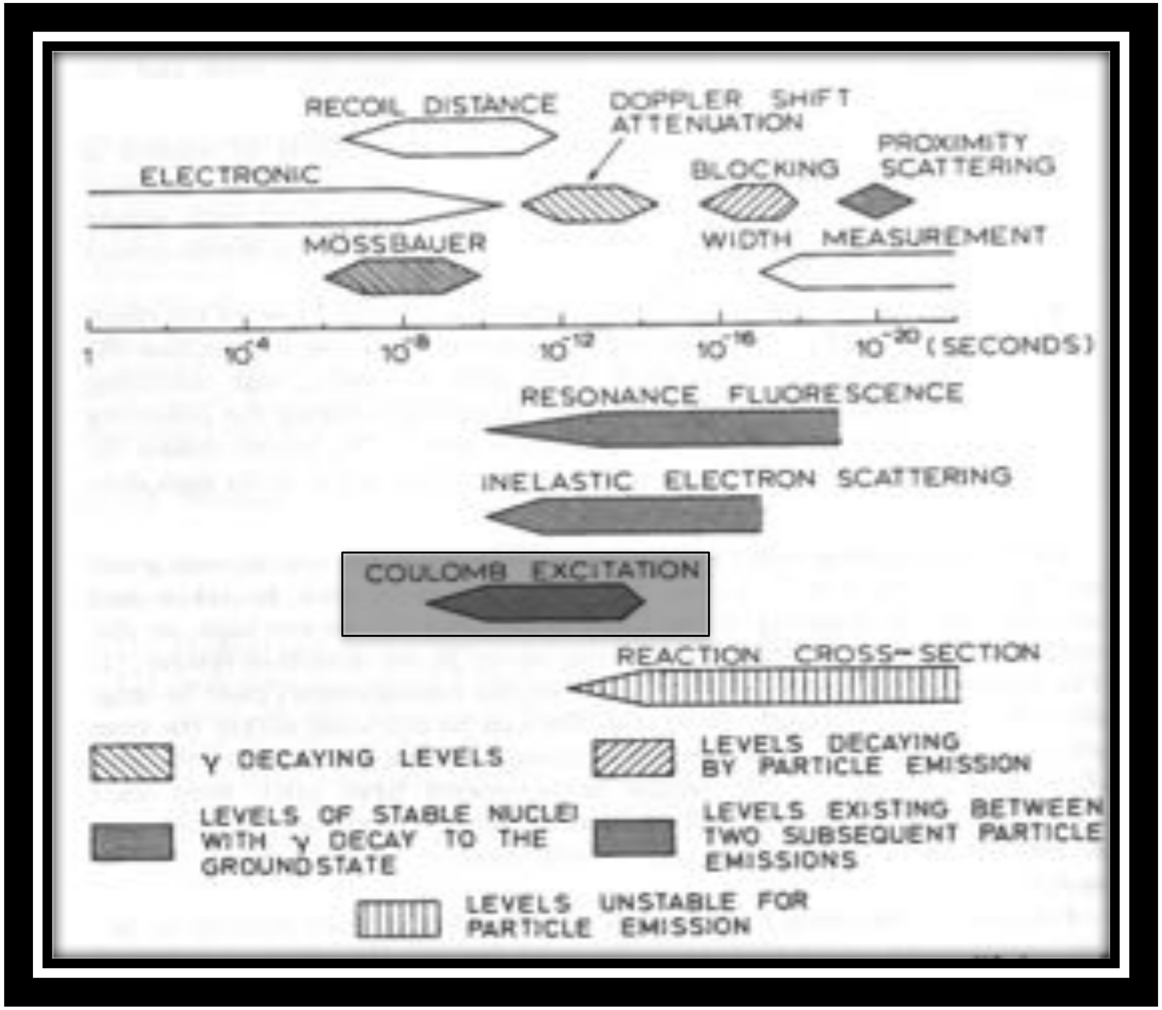
4. Coulomb excitation (with RIBs)

Coulomb excitation is a well known time-dependent EM process that excites atomic nuclei. Kinetic energy is transferred to excitation energy of involved nuclei.



With Coulomb excitation one can extract the matrix element from measured quantities independent of any model.

$$B(E2; I_1 \rightarrow I_2) = \frac{1}{2I+1} \left| \left\langle I_2 \middle\| \hat{O}(E2) \middle\| I_1 \right\rangle \right|^2$$

measurement

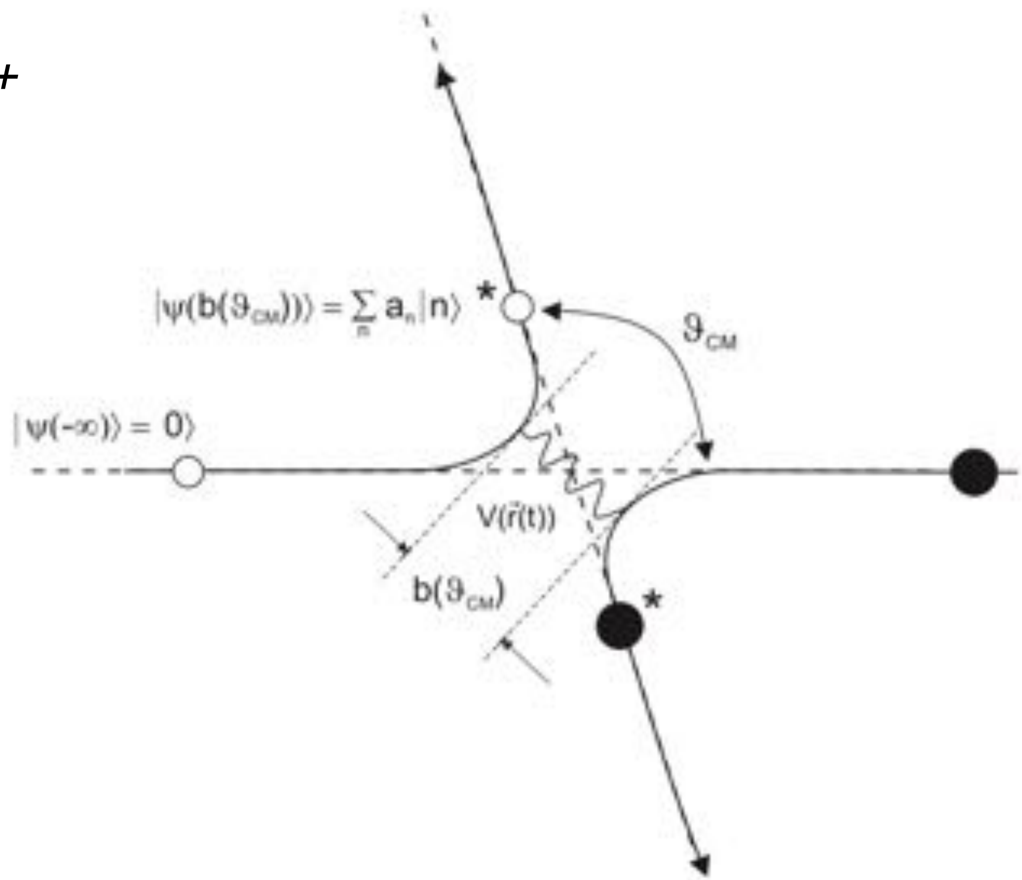
Next we will see how it is done in collisions between two nuclei.

Kinematics of Coulomb excitation

Inelastic collision between bombarding and target nucleus. CoulEx is present in wide energy range, however in experiments, \`safe´ energy is chosen

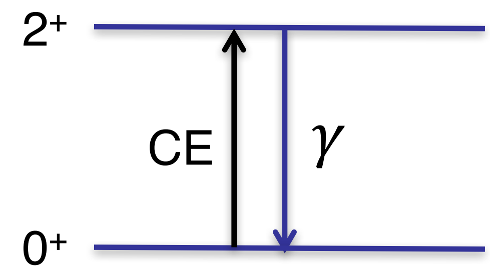
\`Safe´ Coulomb excitation condition:

- Distance of the closest approach $b(\theta) \geq R_1 + R_2 + \Delta$, where $\Delta = 5$ fm.
- Then influence of the nuclear force can be neglected (< 0.1%) . This means that genuine nuclear reactions are not present.



Since Coulomb excitation populates excited states, depopulating γ rays can be measured. Gamma-ray intensity allows determination of EM matrix elements. Cross section, first order perturbation theory (for a single excitation, no other couplings):

$$d\sigma_{E\lambda} = \left(\frac{Z_P e}{\hbar v}\right)^2 a^{-2\lambda+2} B(E\lambda; I_0 \rightarrow I_f) df_{E\lambda}(\theta,\xi)$$



Cross section σ is proportional to the measured γ-ray intensity.

Relative measurement can be done since the target excitation is well known. No need to correct for absolute beam dose, absolute detector efficiency or target thickness:

$$\sigma_{projectile} = \frac{N_{\gamma,projectile}}{N_{\gamma,target}} \cdot \frac{\varepsilon_{\gamma,target}}{\varepsilon_{\gamma,projectile}} \cdot \frac{W_{\gamma,target}}{W_{\gamma,projectile}} \cdot \sigma_{target}$$

Second order perturbation theory and nuclear reorientation:

$$\sigma_{CE}\left(I_i \rightarrow I_f\right) \propto \left\langle I_f \left\| \hat{O}(E2) \right\| I_i \right\rangle^2 \cdot \left[1 - \left\langle I_f \left\| \hat{O}(E2) \right\| I_f \right\rangle \cdot f(\zeta)\right]$$

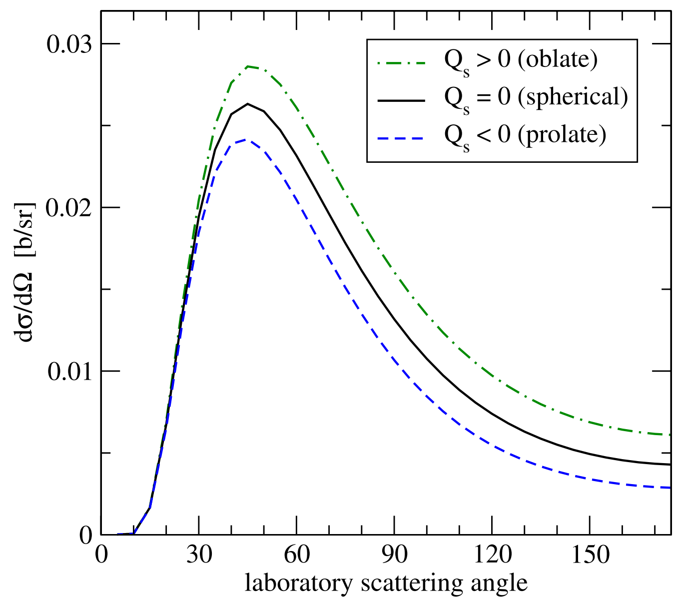
Tabulated

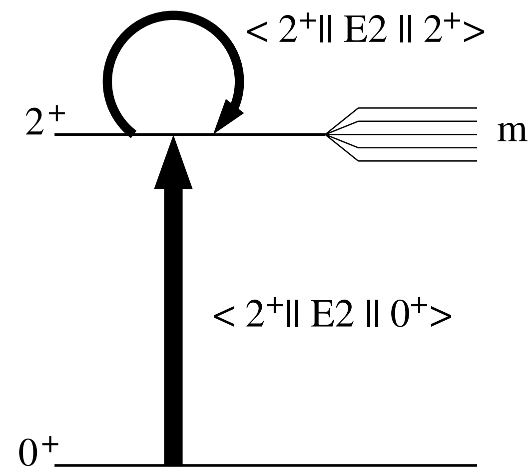
Transition matrix element $\propto$ $B(E2)$ value

Diagonal matrix element $\propto$ Q_0

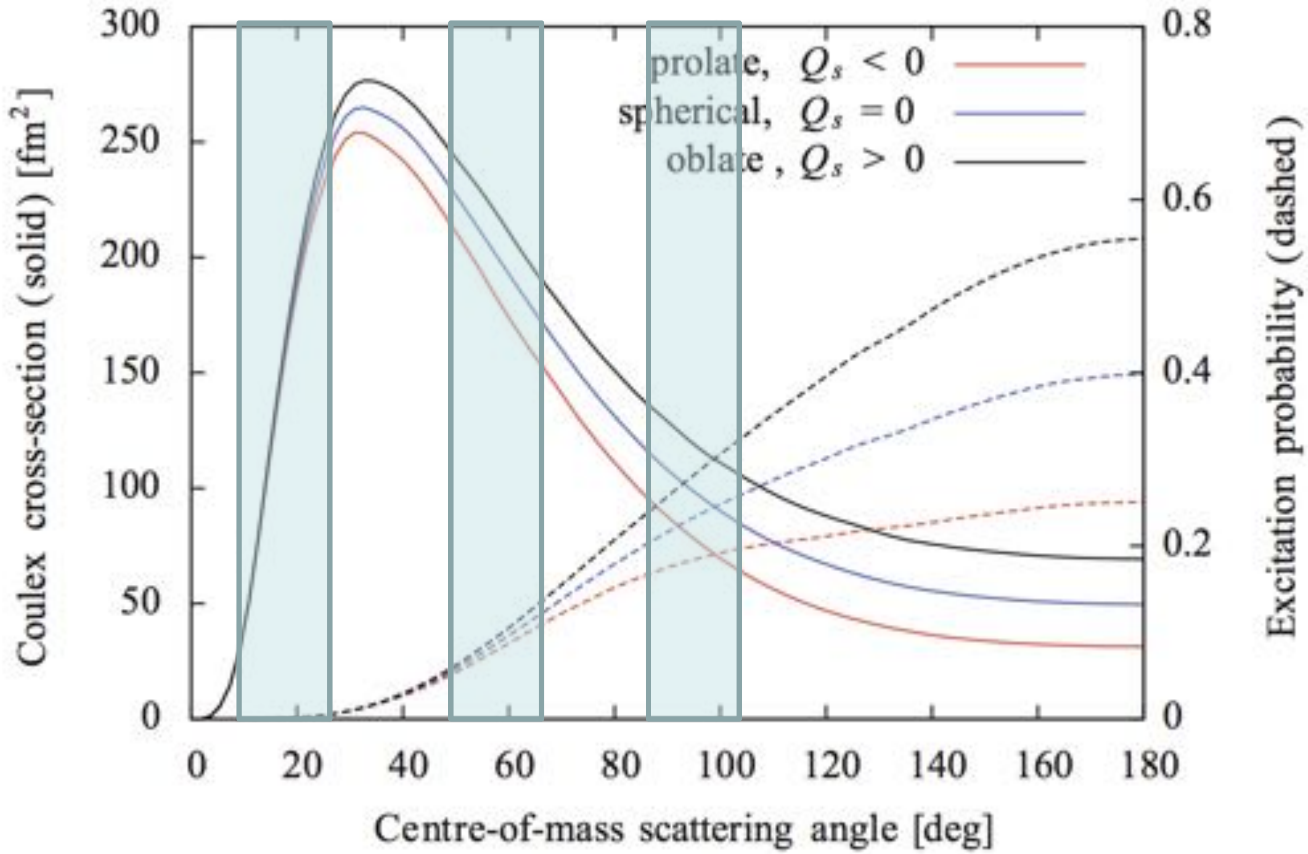
Unknowns

Two unknowns–at least two independent measurement required.



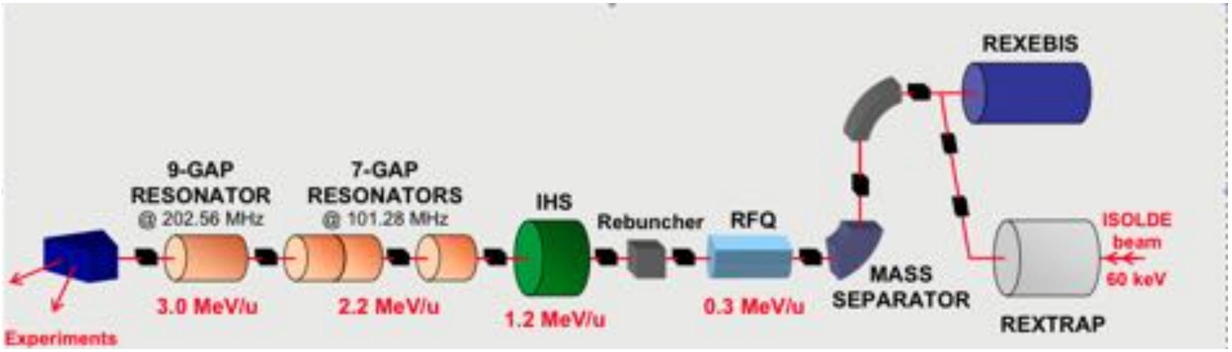


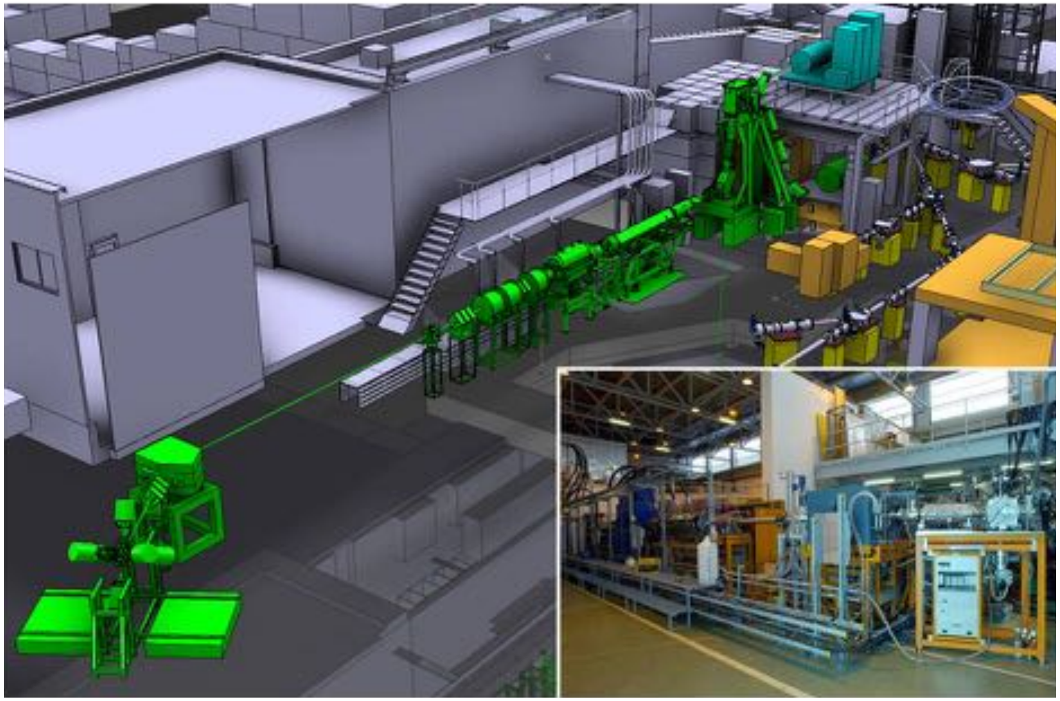
Different experiments can be different angular ranges of particle detection…

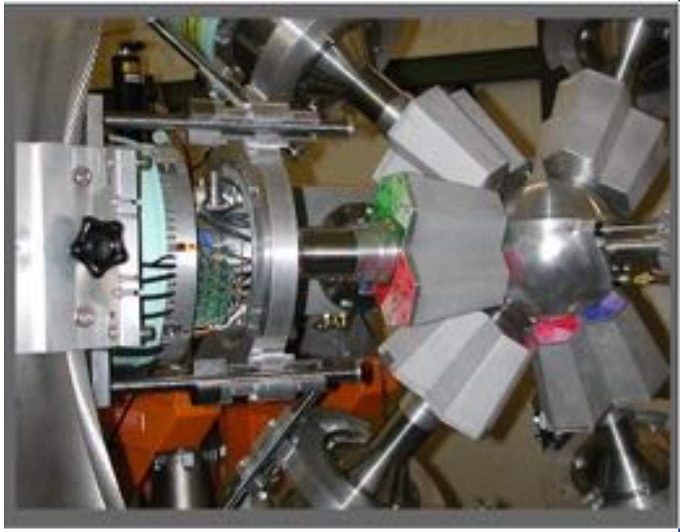


…or experiments with different beam energies or with different targets.
⇒a set of equations to be solved.

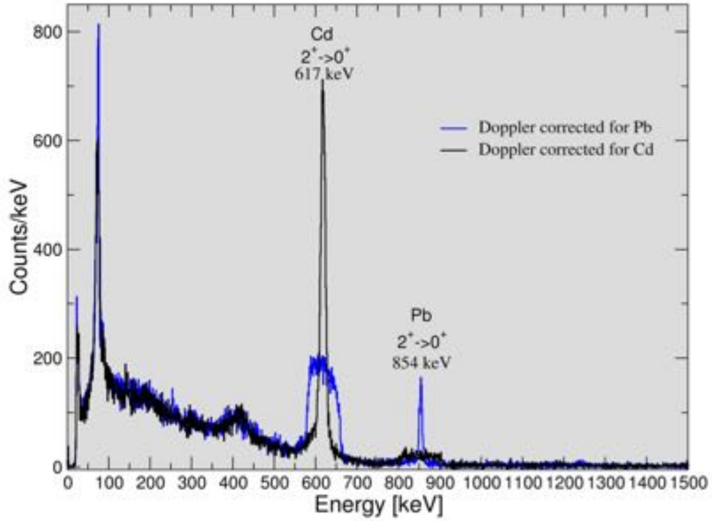
Production of RIBs at CERN-ISOLDE



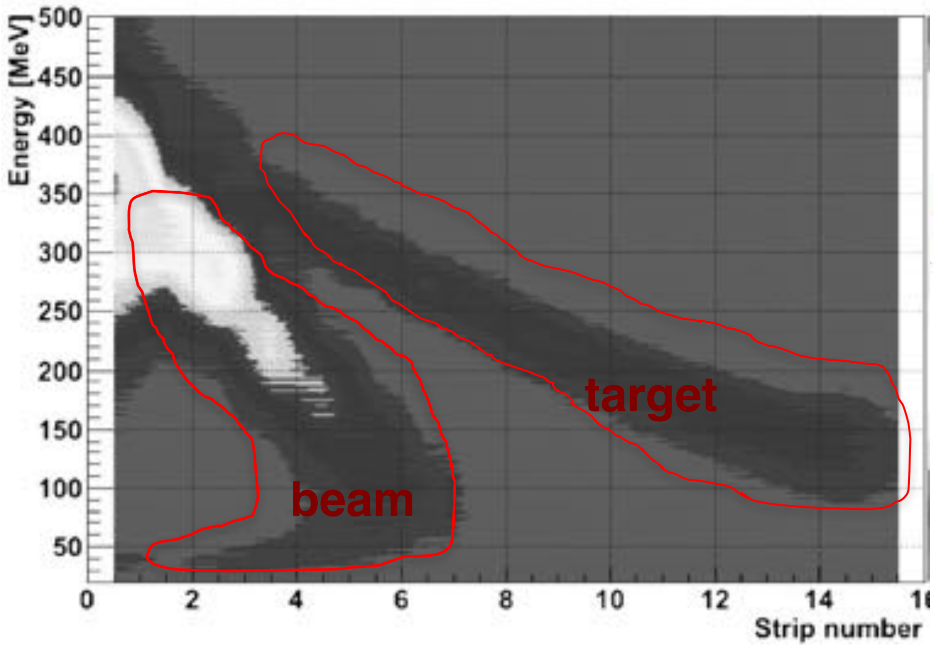


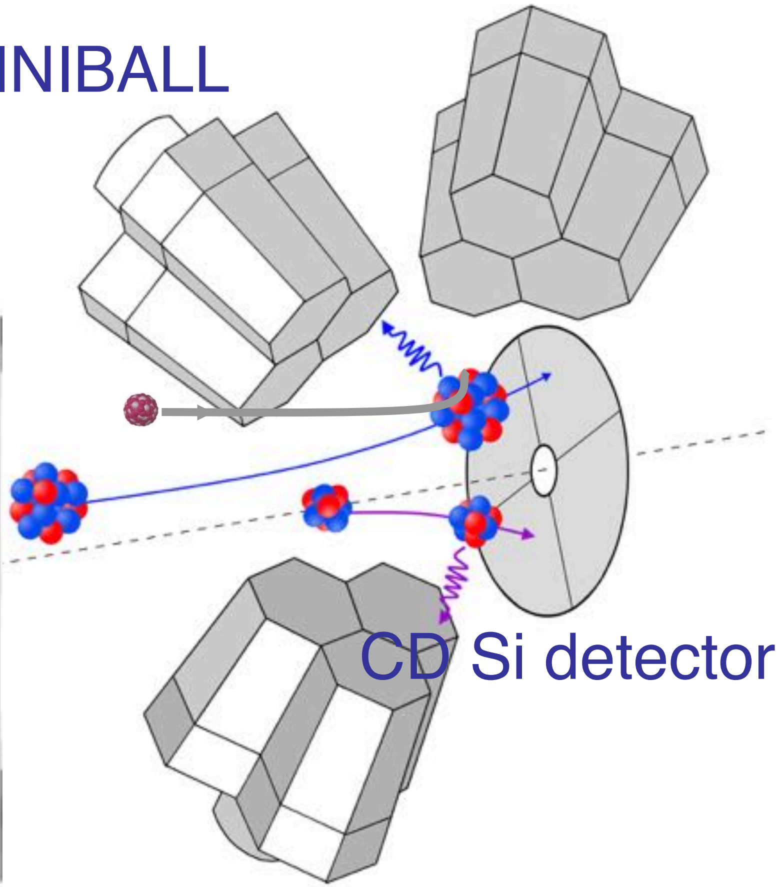


Identification of Coulomb excitation events

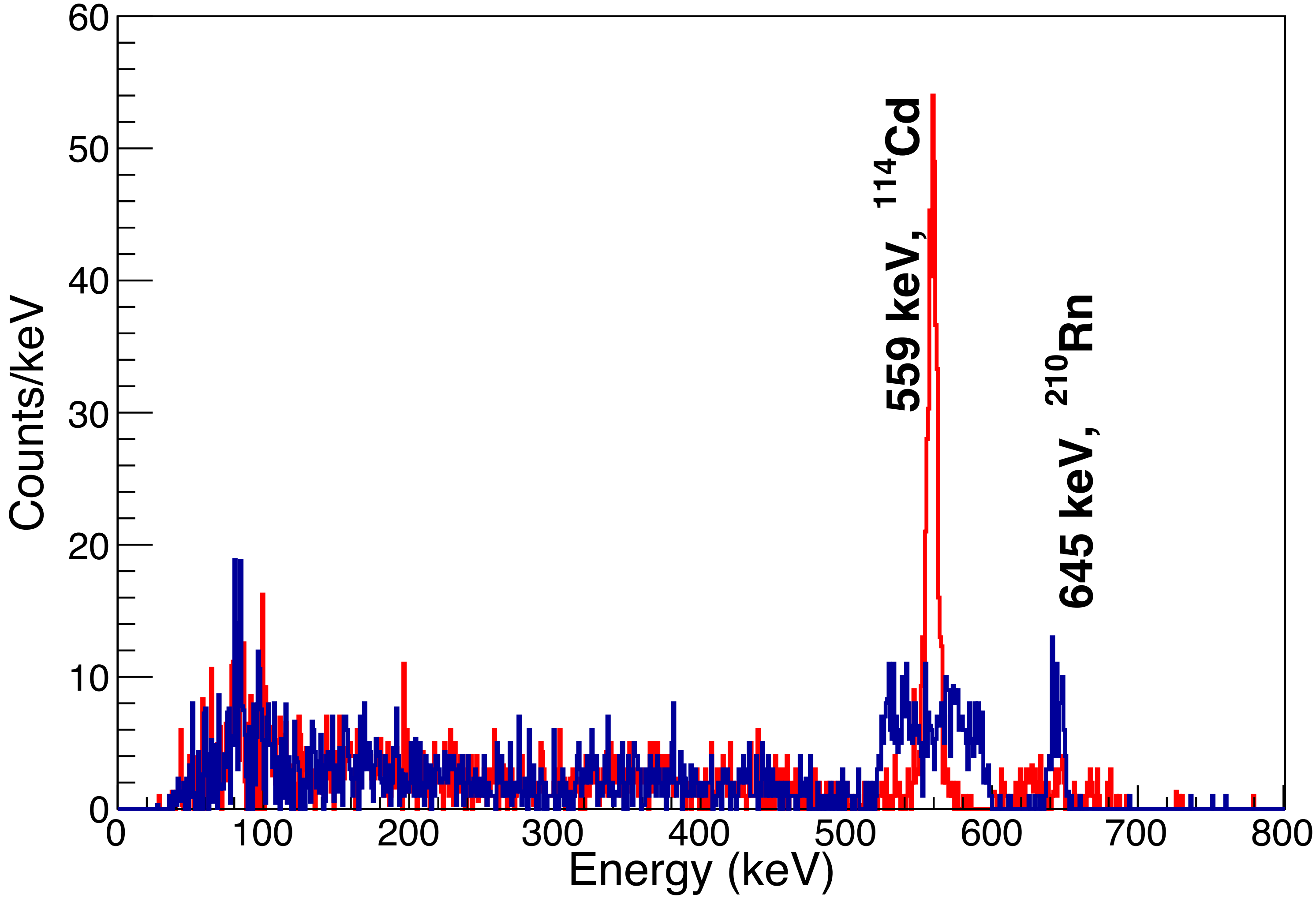


CoulEx of radioactive ^{190}Pb at REX-ISOLDE at CERN



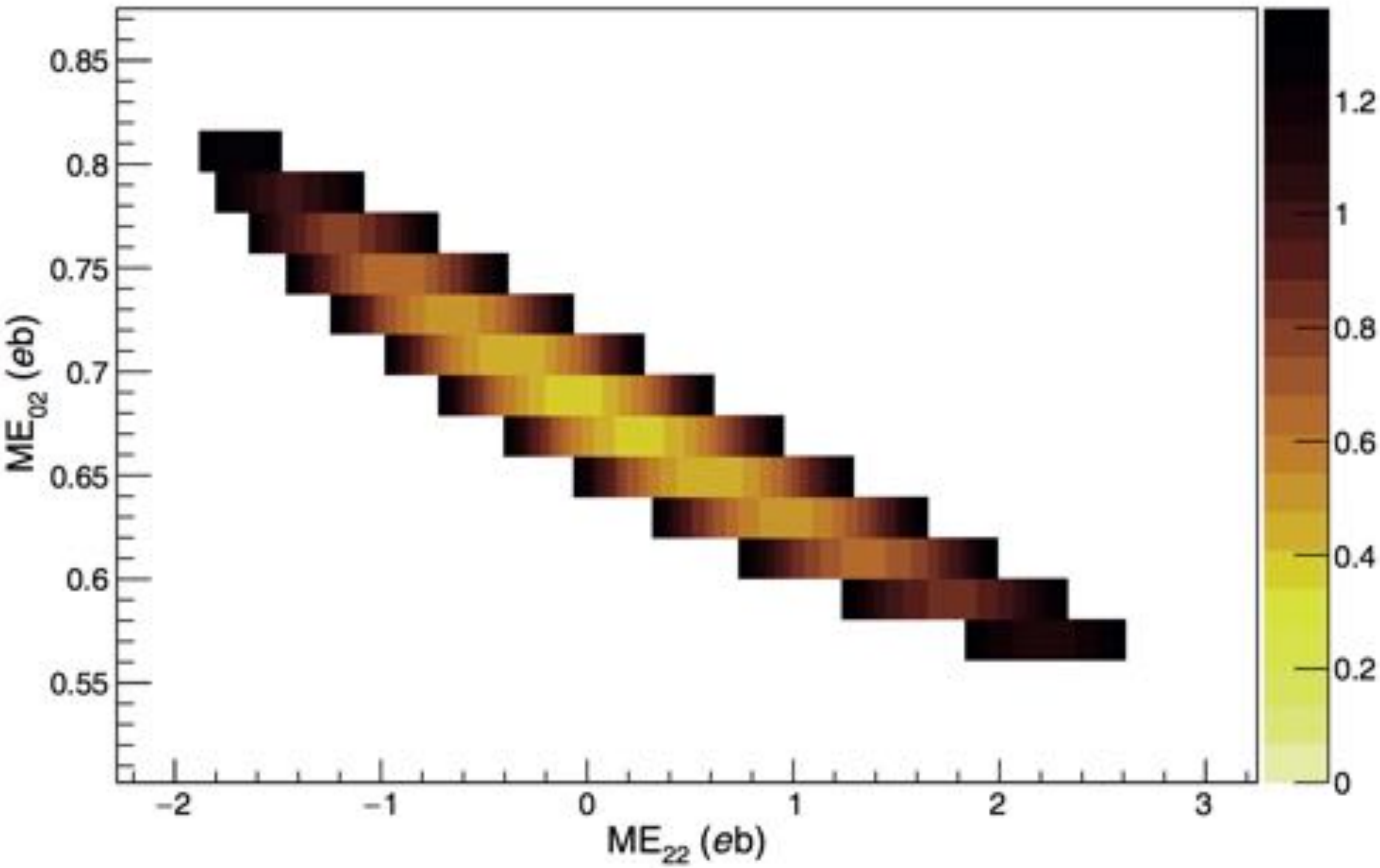


^{210}Rn beam on ^{114}Cd target at REX-ISOLDE, event-by-event Doppler corrected



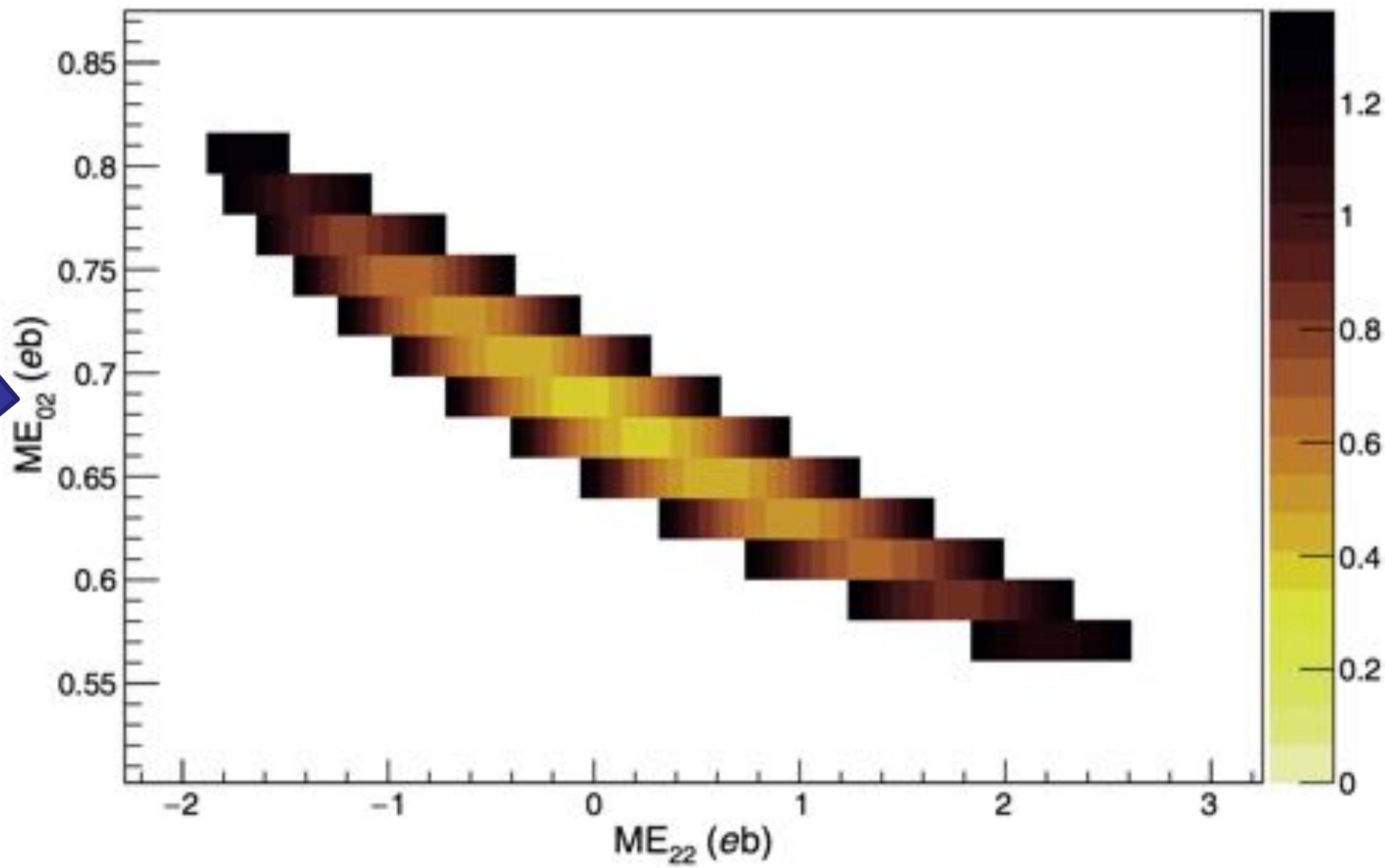
Vary the both matrix elements and find the values which best reproduce the data (χ^2 analysis)

$$\sigma_{CE}\left(I_i \rightarrow I_f\right) \propto \left\langle I_f \middle\| \hat{O}(E2) \middle\| I_i \right\rangle^2 \cdot \left[1 - \left\langle I_f \middle\| \hat{O}(E2) \middle\| I_f \right\rangle \cdot f\left(\zeta\right)\right]$$



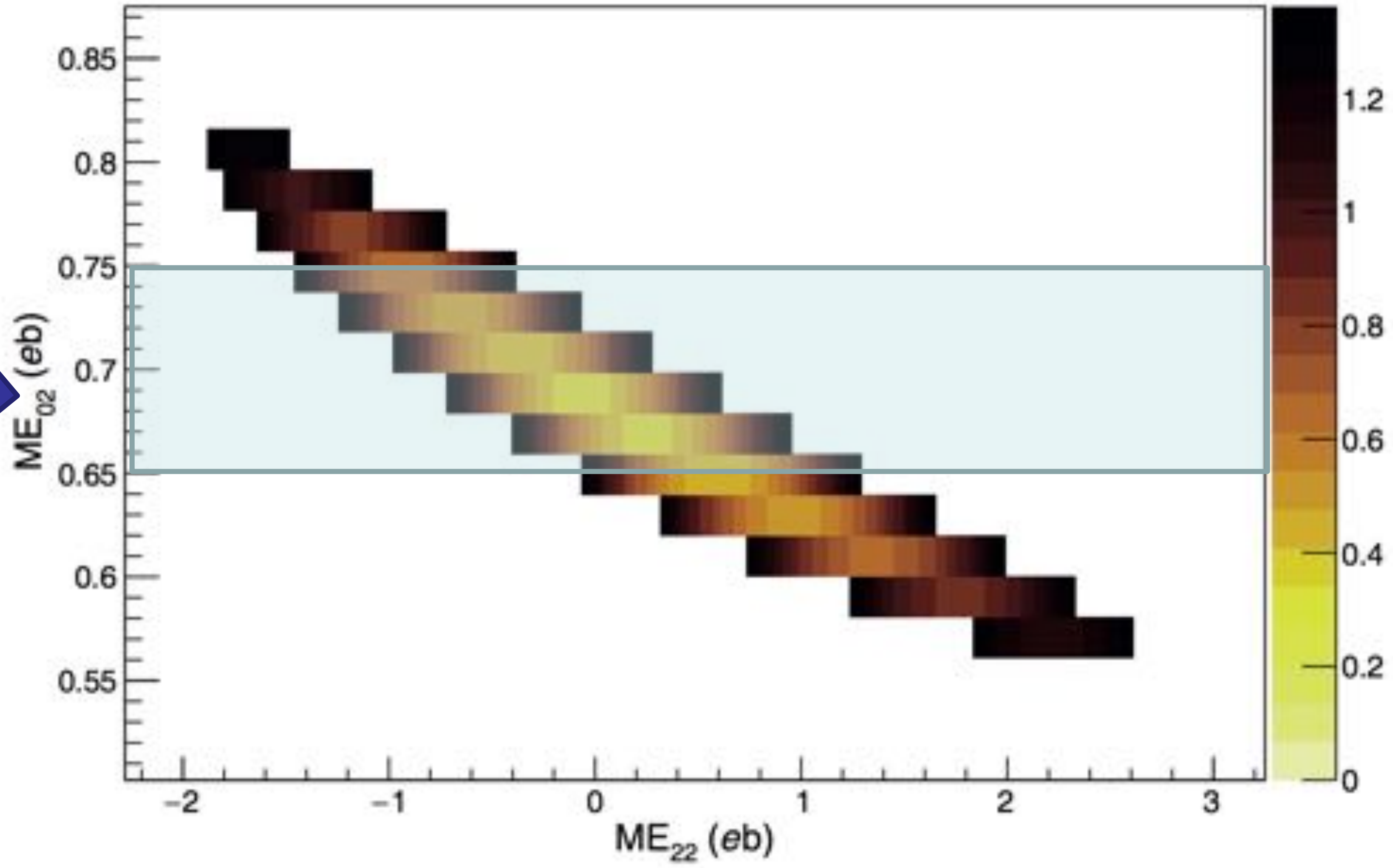
What if we knew the lifetime? This would help the analysis as we can fix one of the unknowns

Proportional to the lifetime



What if we knew the lifetime? This would help the analysis as we can fix one of the unknowns

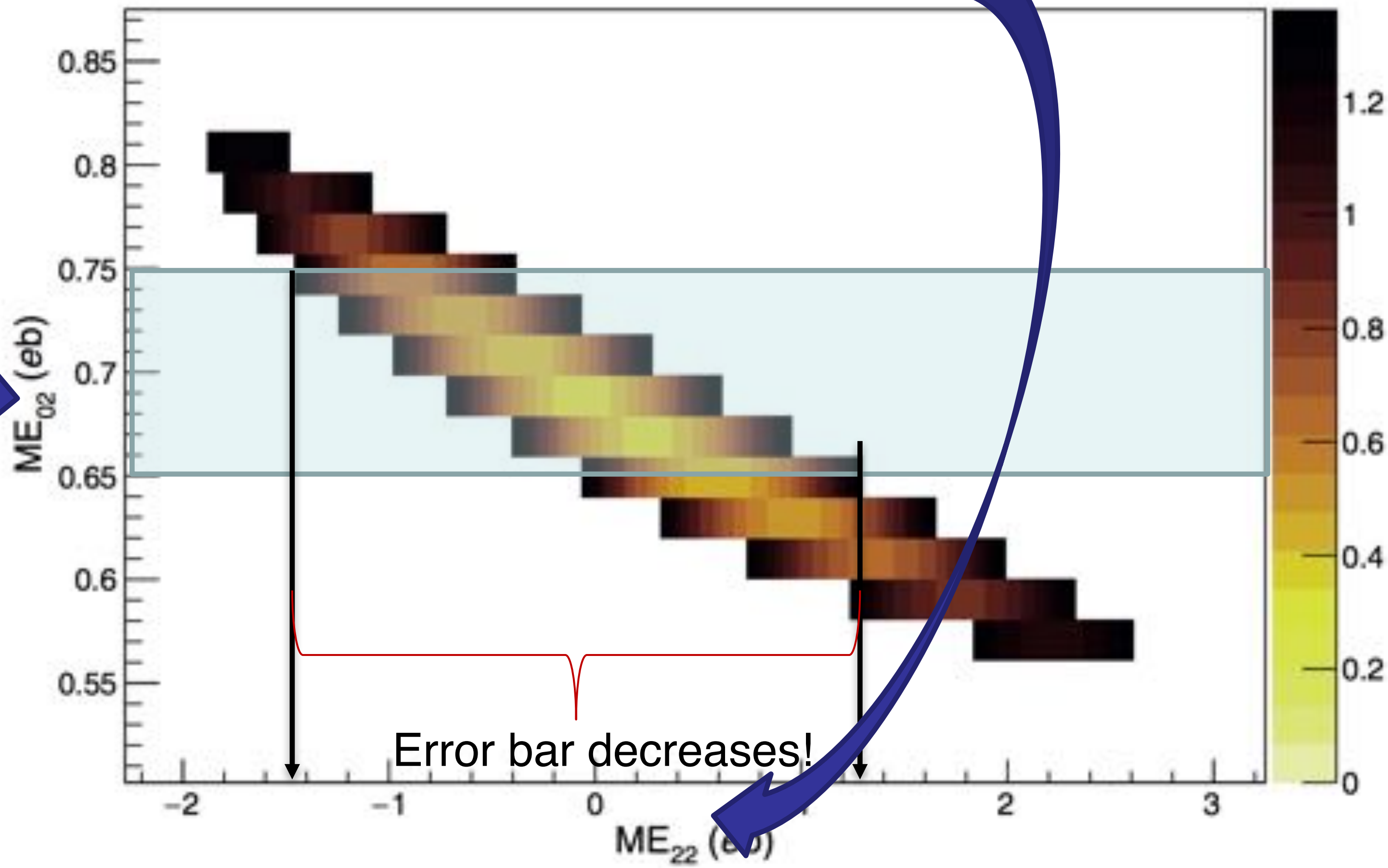
From lifetime, including the error bar



What if we knew the lifetime? This would help the analysis as we can fix one of the unknowns

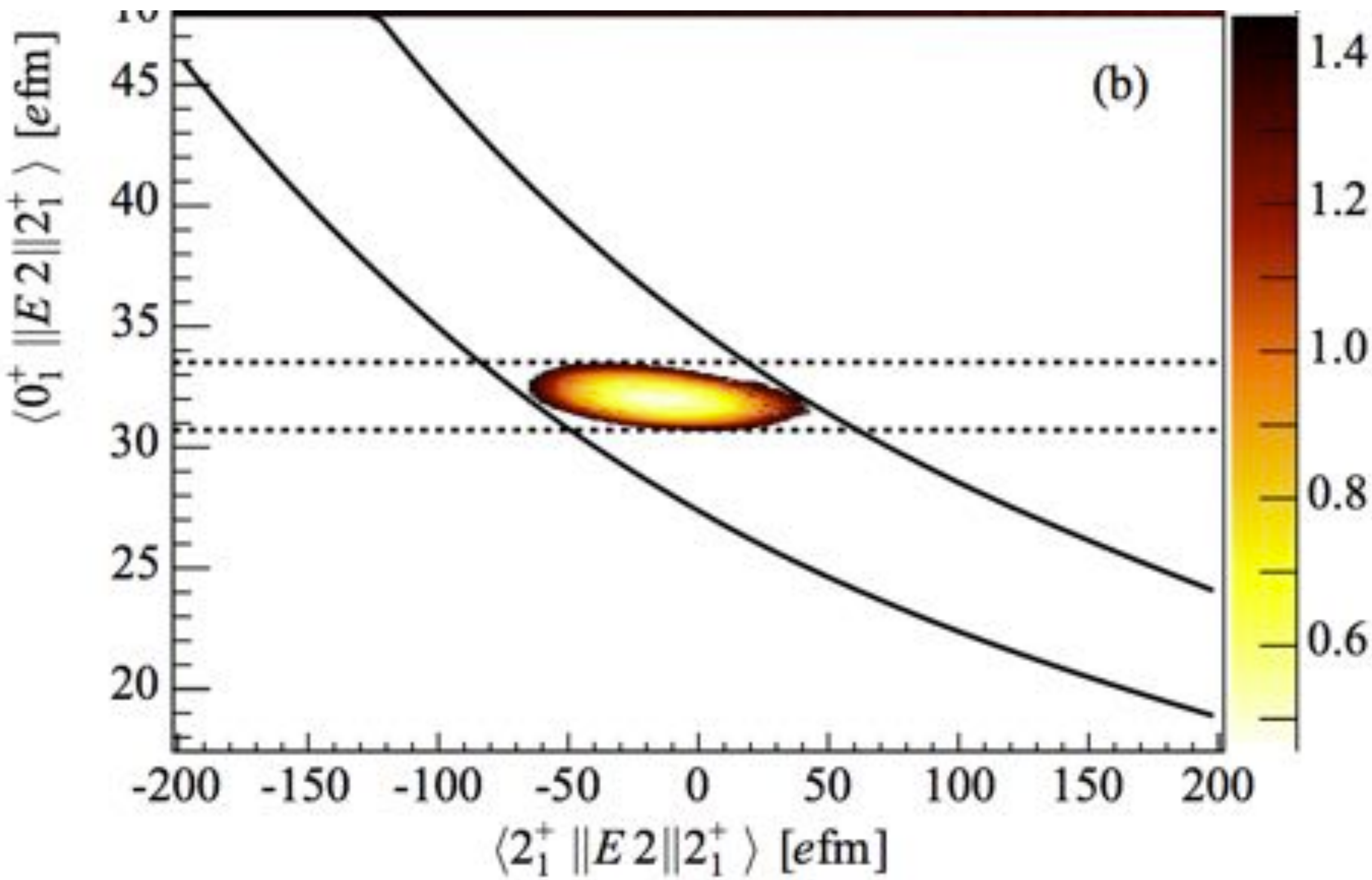
From lifetime, including the error bar

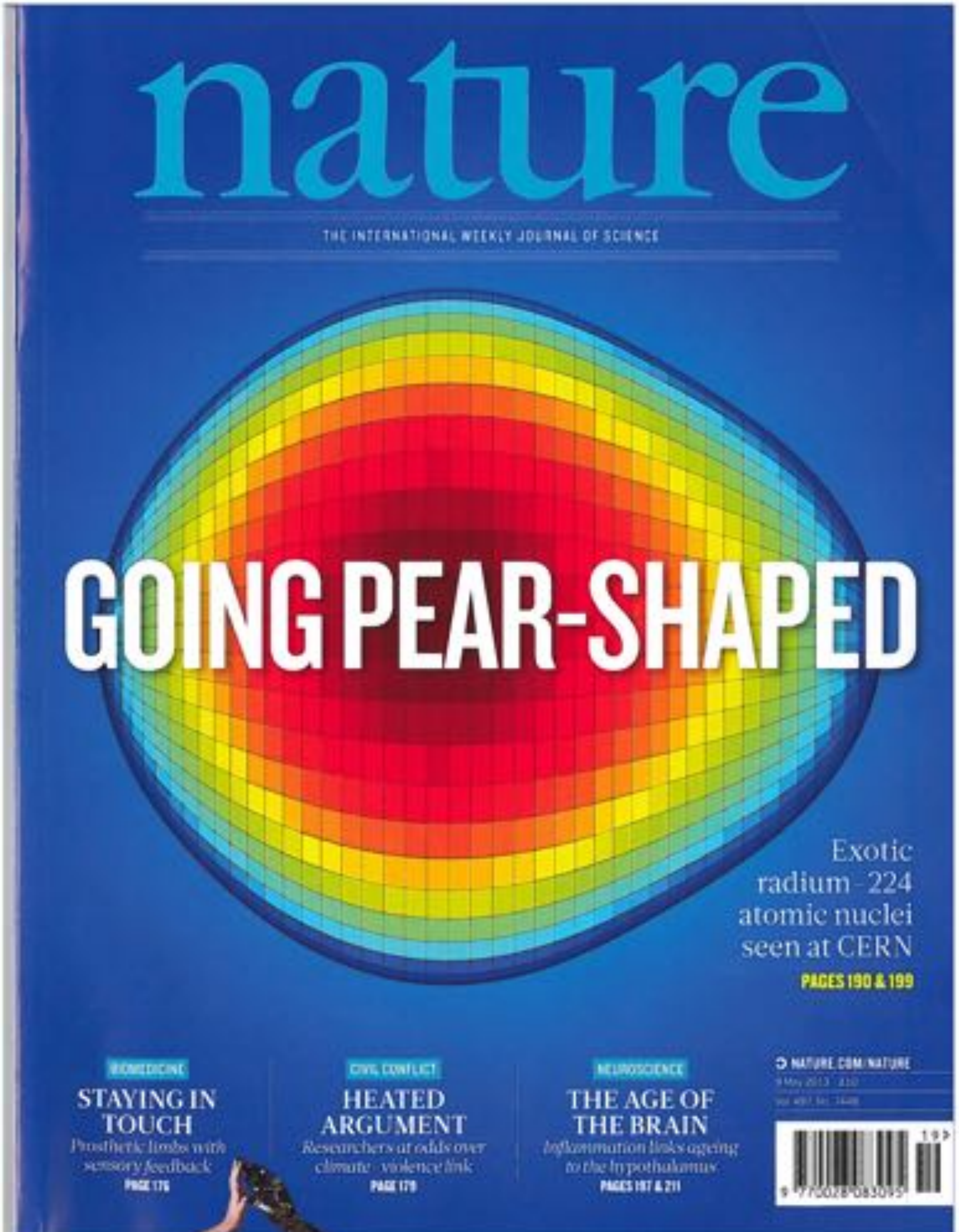
$\propto Q_s$



Error bar decreases!

Lifetime measurements & Coulomb excitation combined





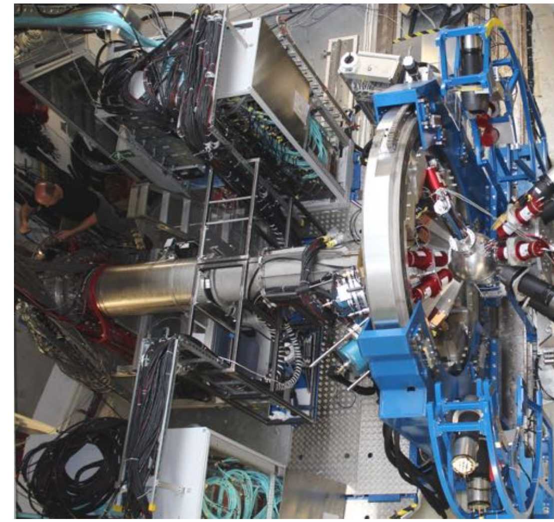
Matrix elements by Coulomb excitation gives us information on the shape of the nucleus. Such as in the case of ^{224}Ra.

Coulomb excitation at relativistic energies

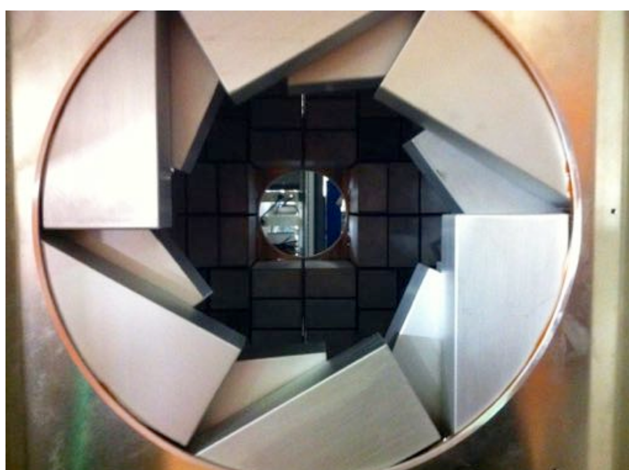
Radioactive beams produced with fragment separators have *v*~0.5c.
Such energetic beams are not safe so CoulEx events have to be chosen with ancillary detectors

Also at NSCL, MSU, East Lansing

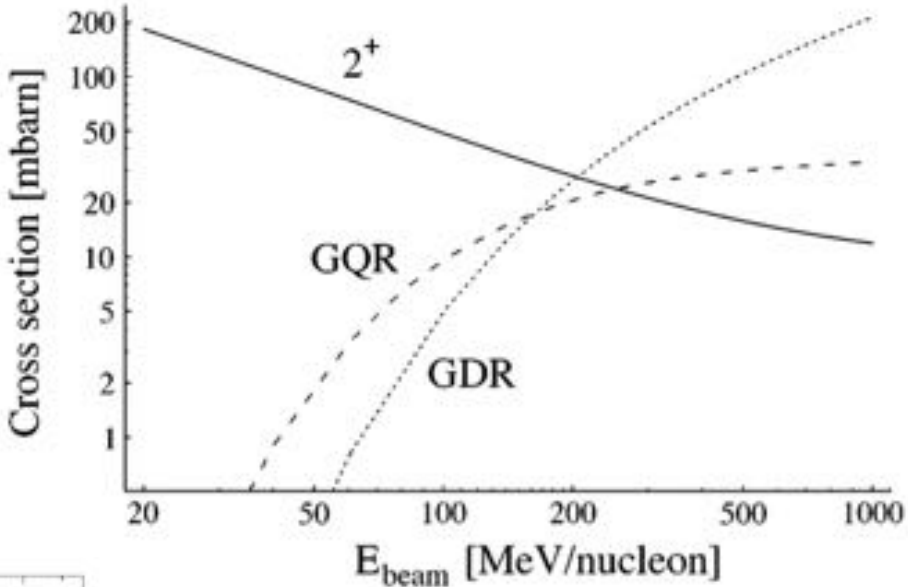
AGATA at FRS at GSI, Darmstadt



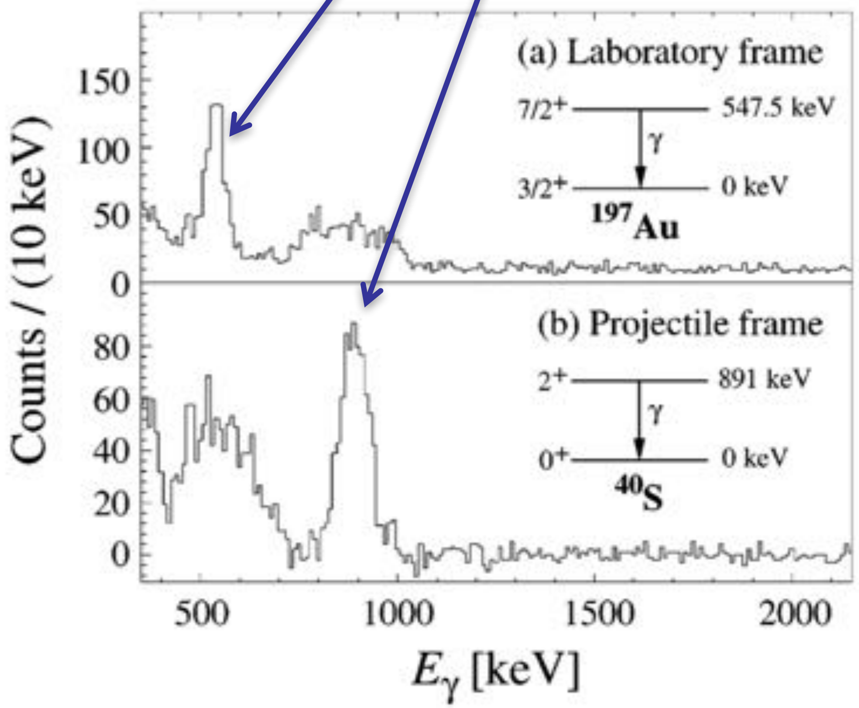
DALI2 at BigRIPS, RIKEN, Tokyo

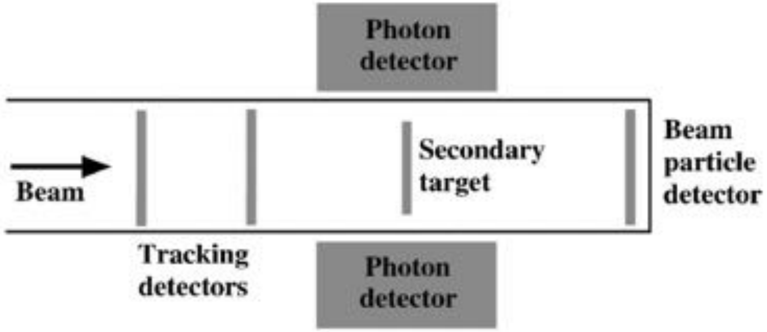


Relativistic Coulomb excitation is a one-step process. (c.f. multi-steps at safe energies.)
Reaction probability is high, but selecting CoulEx events is challenging.



Doppler correction for:
Target and beam





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