Institut für Kernphysik
S|DALINAC
Technische Universität Darmstadt

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One- and two-phonon mixed-symmetry states in ^{94}Mo in high-resolution electron and proton scattering*

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Identification of Mixed-Symmetry States: Interacting Boson Model - 2

- Pairing of nucleons to s-/ d-bosons

- F-Spin: boson: $F_0 = 1/2$
  boson: $F_0 = -1/2$
  $\frac{|N - N|}{2} \quad F \quad F_{max} = \frac{N + N}{2}$

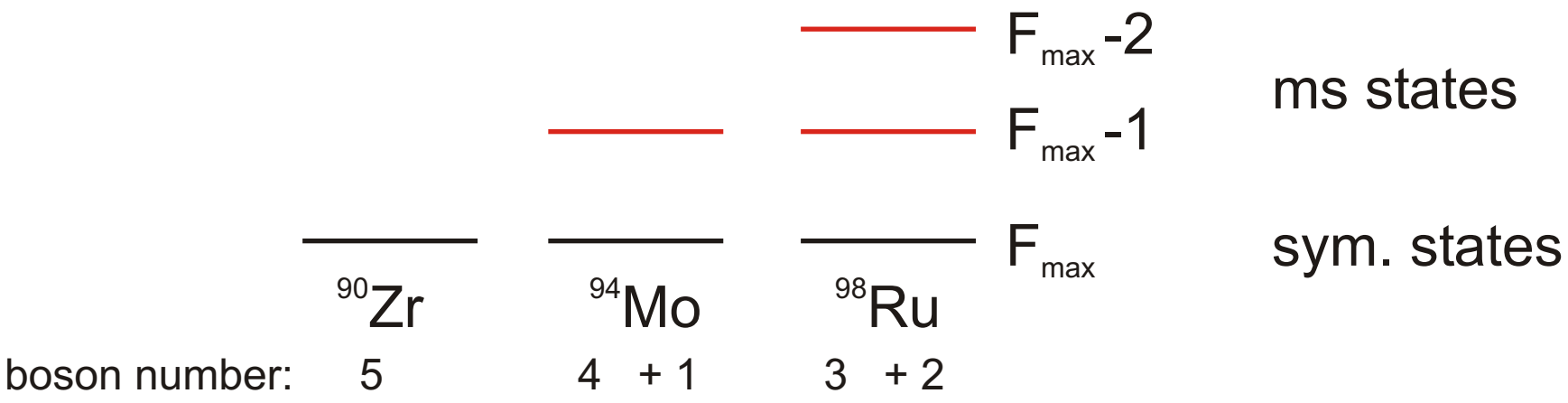
  $F = F_{max}$: symmetric states

  $F < F_{max}$: mixed-symmetry states (ms)

- Q-Phonon scheme: $Q_s = Q + Q$ $\quad |\, 2_1^+ \quad Q_s \,|\, 0_1^+$

  $Q_{ms} = \frac{N}{2}\left(\frac{Q}{N} - \frac{Q}{N}\right) \quad |\, 2_{ms}^+ \quad Q_{ms} \,|\, 0_1^+$

F-Spin Multiplet



Why ^{94}Mo?

- The low-energy spectrum of ^{94}Mo is well studied and candidates for most one- and two-phonon states have been identified

  N. Pietralla *et al.*, Phys. Rev. Lett. 83 (1999) 1303
  N. Pietralla *et al.*, Phys. Rev. Lett. 84 (2000) 3775
  C. Fransen *et al.*, Phys. Lett. B 508 (2001) 219
  C. Fransen *et al.*, Phys. Rev. C 67 (2003) 024307

- Study of 2^+ states with (e,e´) and (p,p´)
  - ⇒ sensitive to one-phonon components of the wave function
  - ⇒ test of fundamental phonon character
  - ⇒ isoscalar / isovector decomposition
  - ⇒ purity of two-phonon states

Experiments

- High resolution required to resolve all 2^+ states below 4 MeV
- Lateral dispersion matching techniques
- (e,e´):
  S-DALINAC, TU Darmstadt

  E_e = 70 MeV
  = 93°- 165°
  E = 30 keV (FWHM)
- (p,p´):
  SSC, iThemba LABS

  E_p = 200 MeV
  = 7°- 26°
  E = 35 keV (FWHM)

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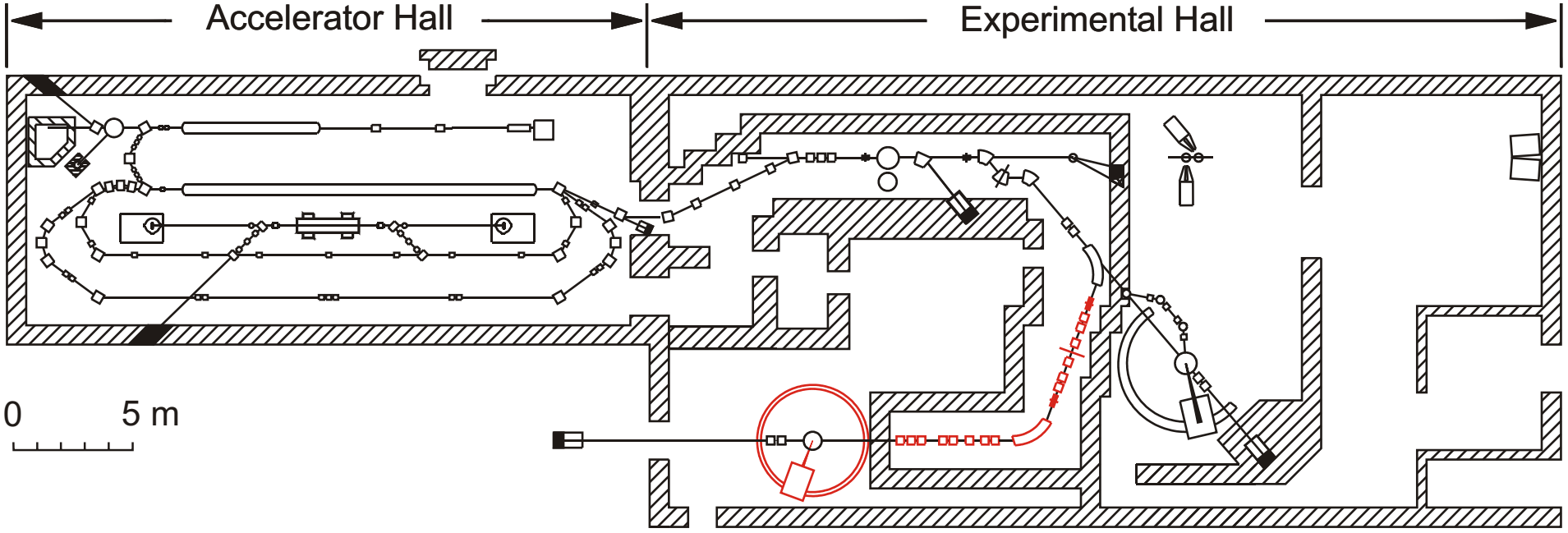
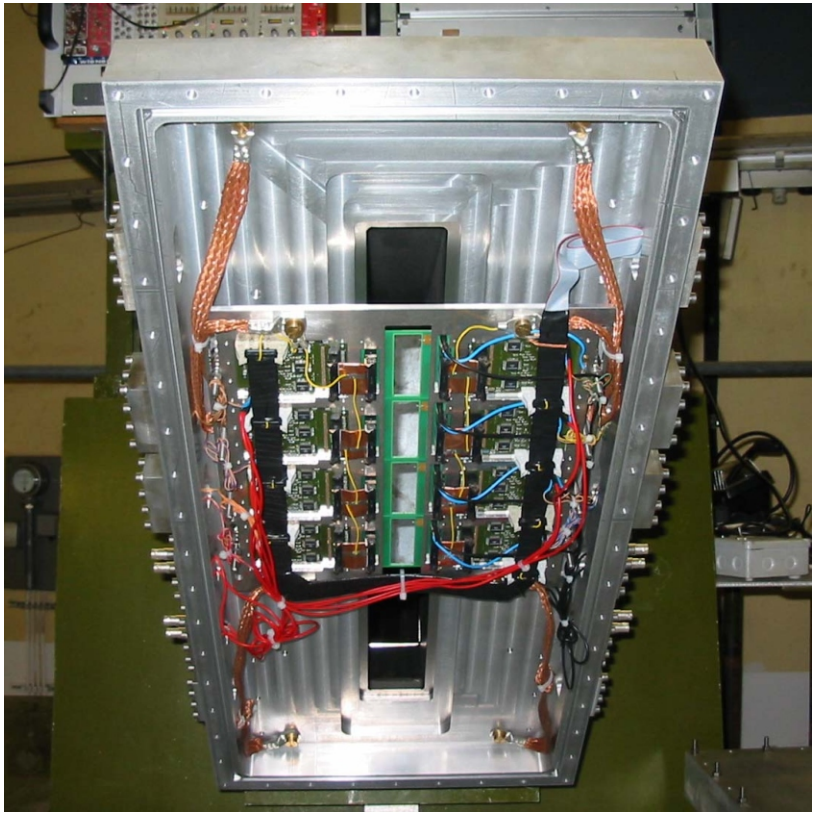


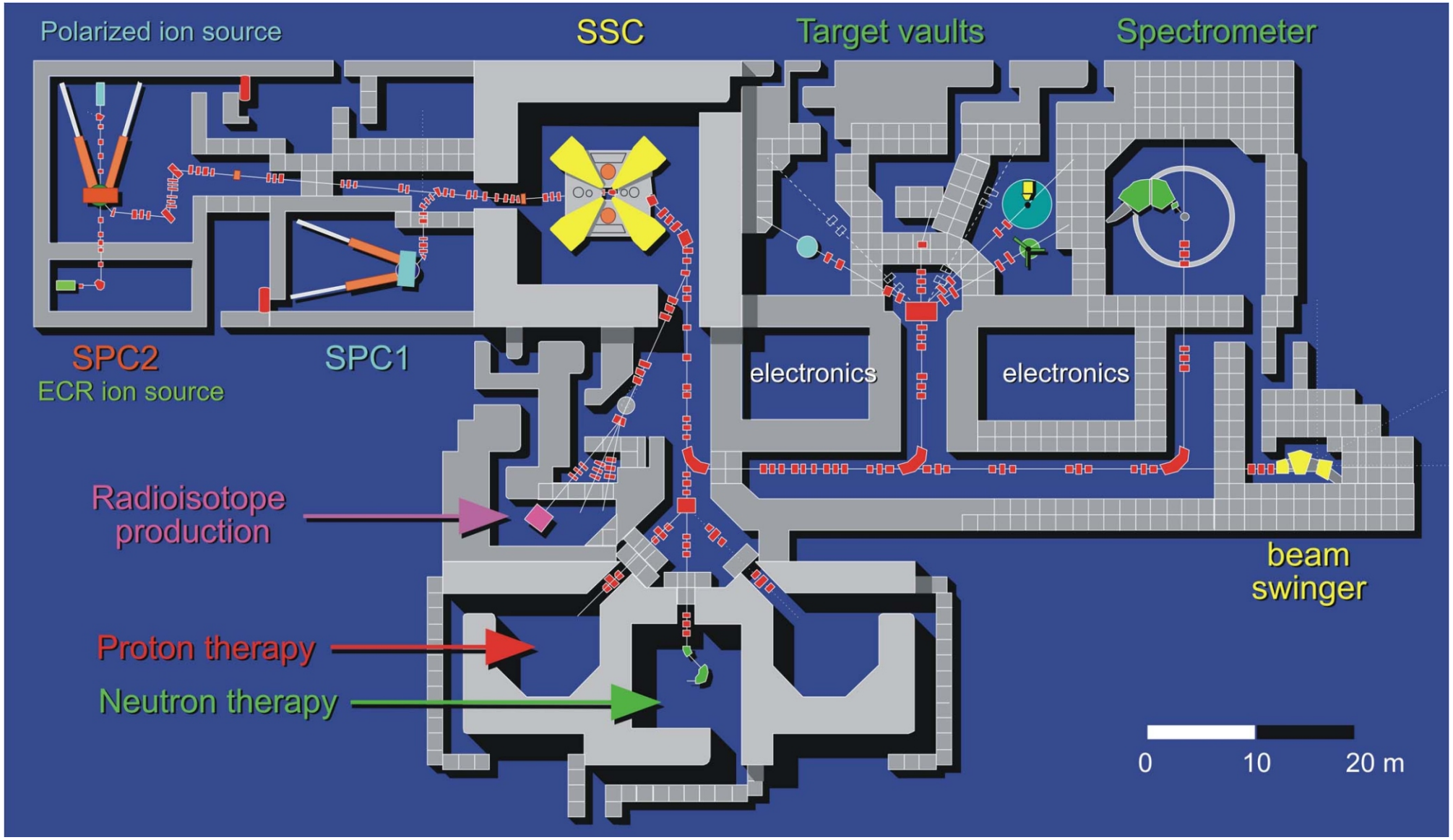
- High-resolution (e,e´) experiments

LINTOTT Spectrometer and Focal Plane Detector System

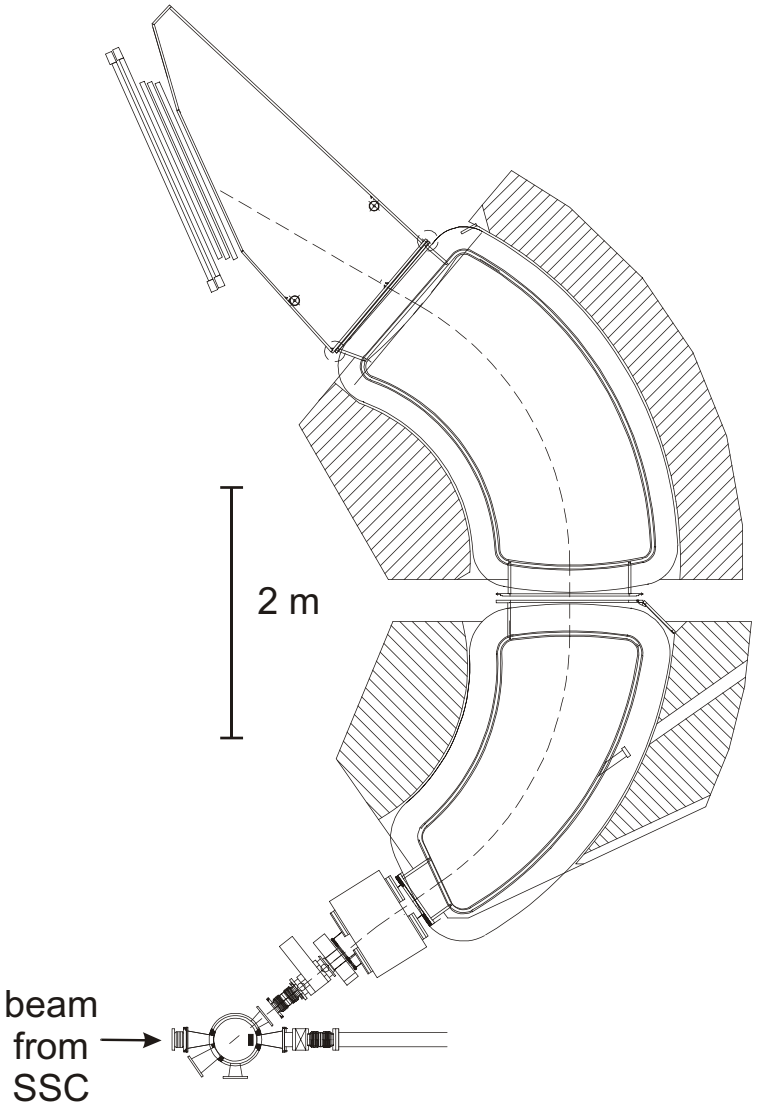


- New Si microstrip detector system: 4 modules, each contains 96 strips with active width of 500 m
- Resolution: $E/E = 4 \times 10^{-4}$
- Data rates up to 100 kHz

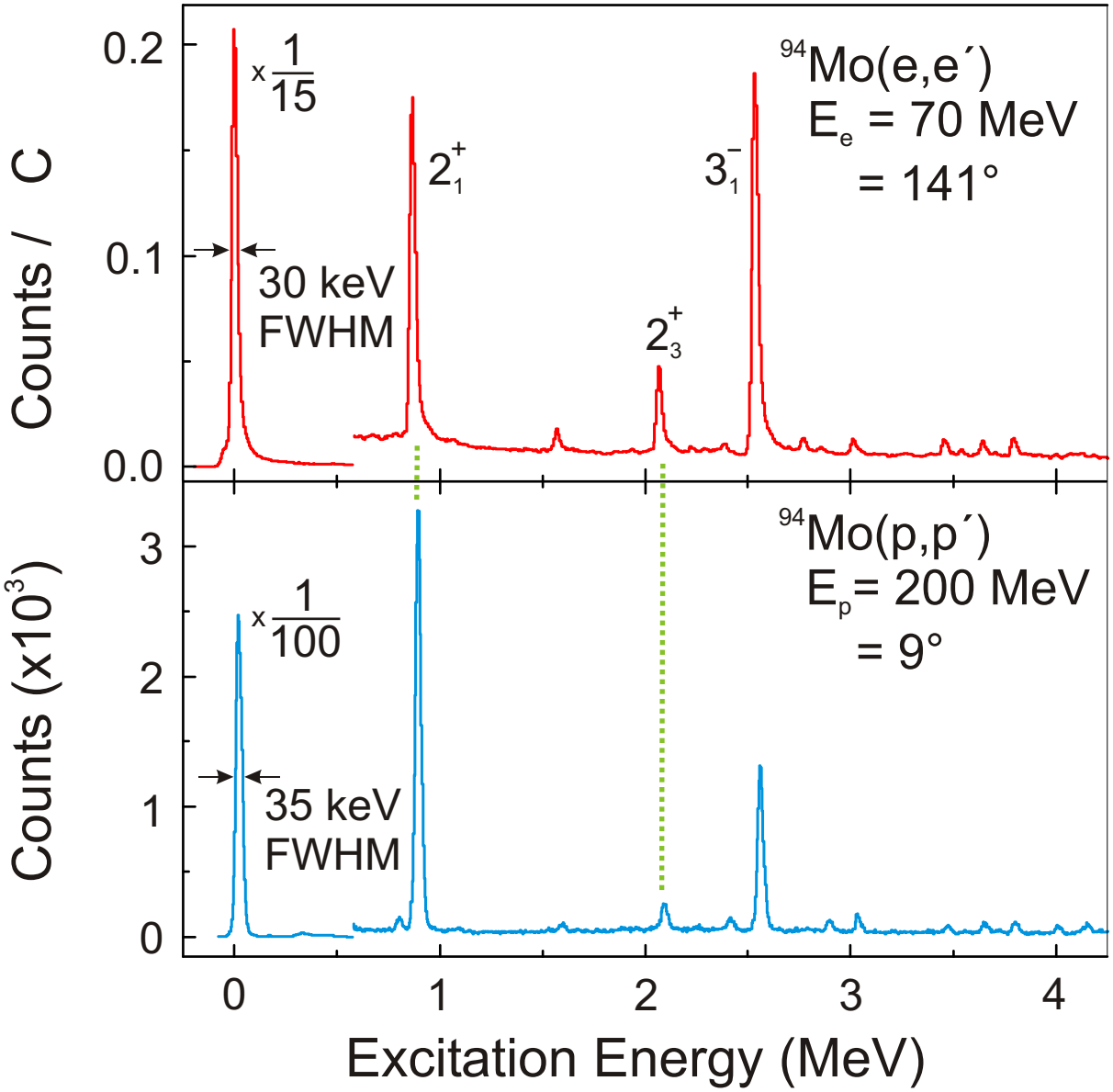
Separated-Sector Cyclotron Facility



K600 Magnetic Spectrometer and Detector System



Measured Spectra



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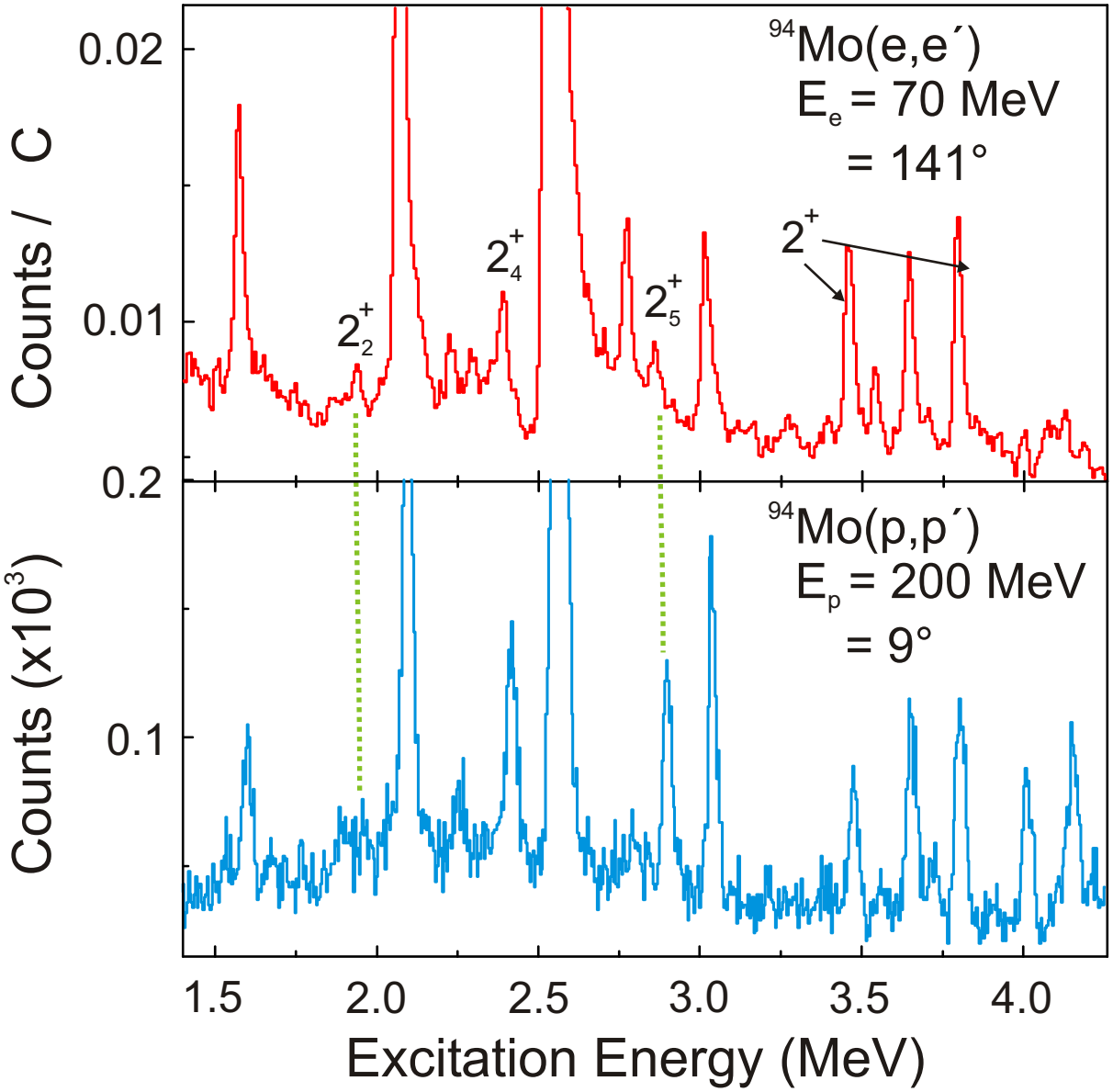
Measured Spectra



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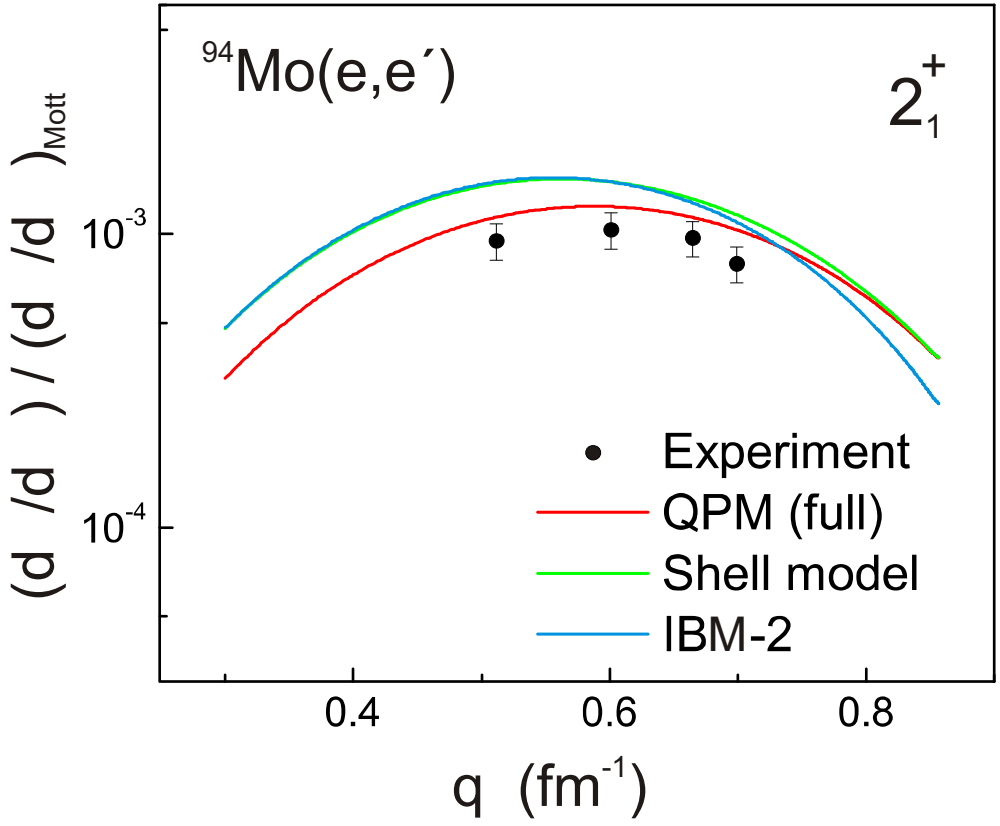
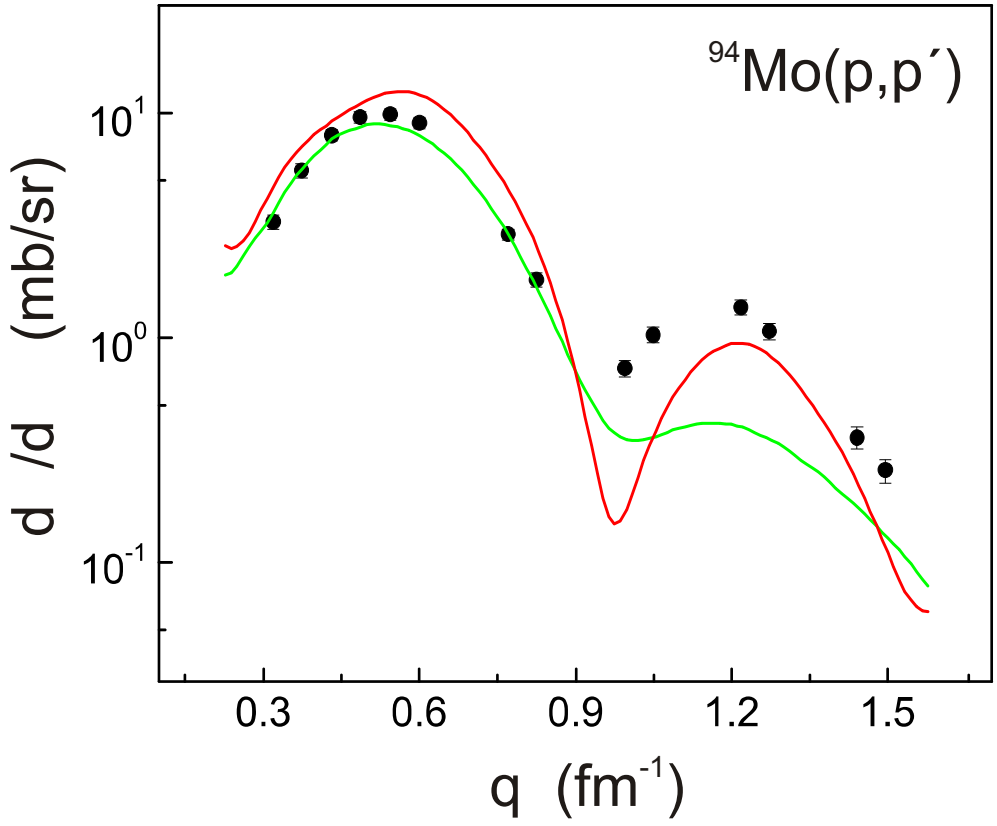
Theoretical Calculation

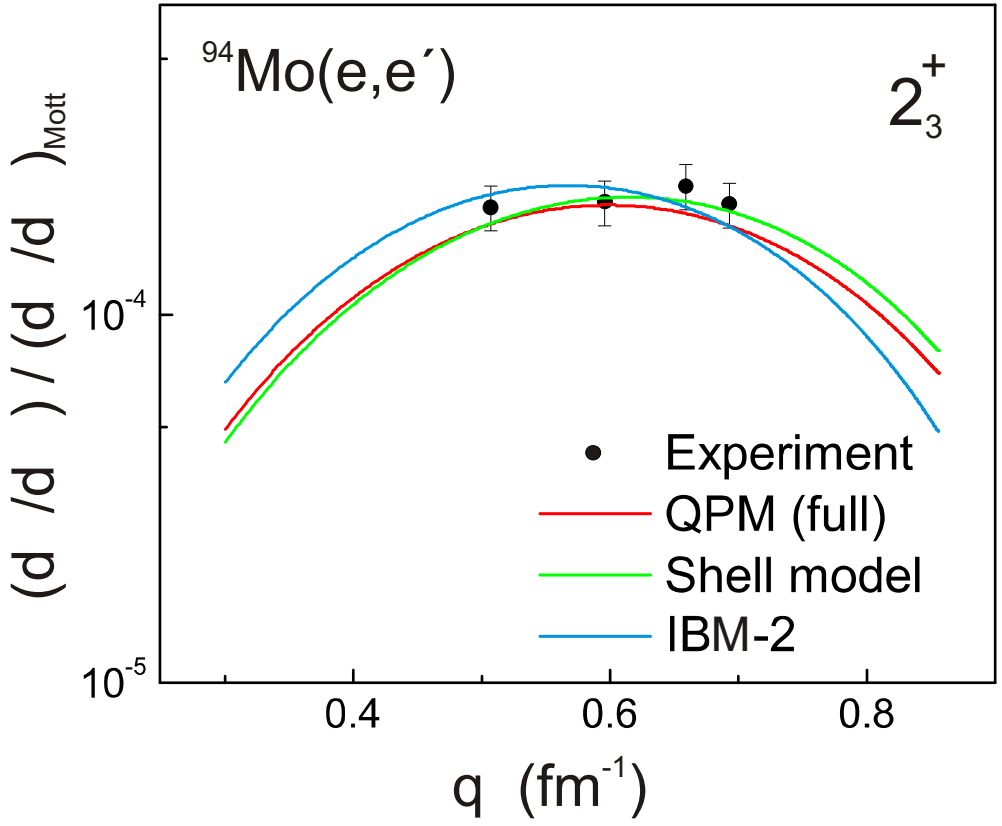
- Quasi-Particle Phonon Model
  ⇒ coupling up to 3 phonons
- Shell Model
  ⇒ ^{88}Sr core / Surface Delta Interaction
- IBM-2
- Cross Sections
  ⇒ DWBA / Love-Franey effective nucleon-target interaction for (p,p´)

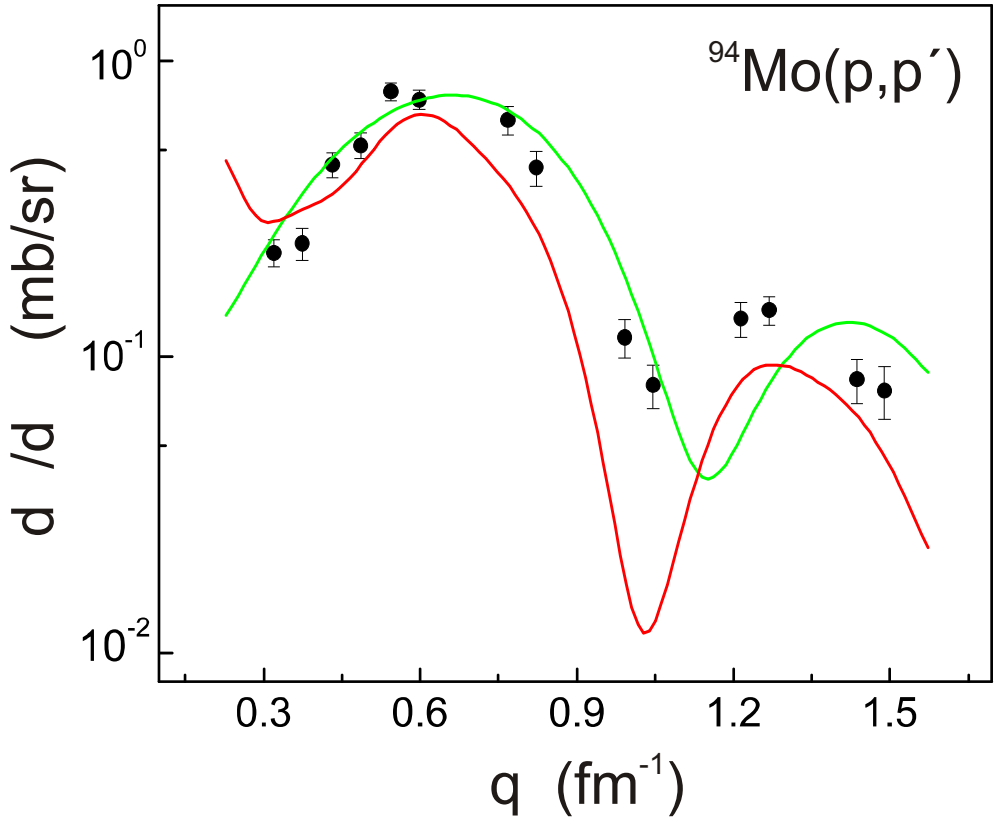
One-Phonon Symmetric State



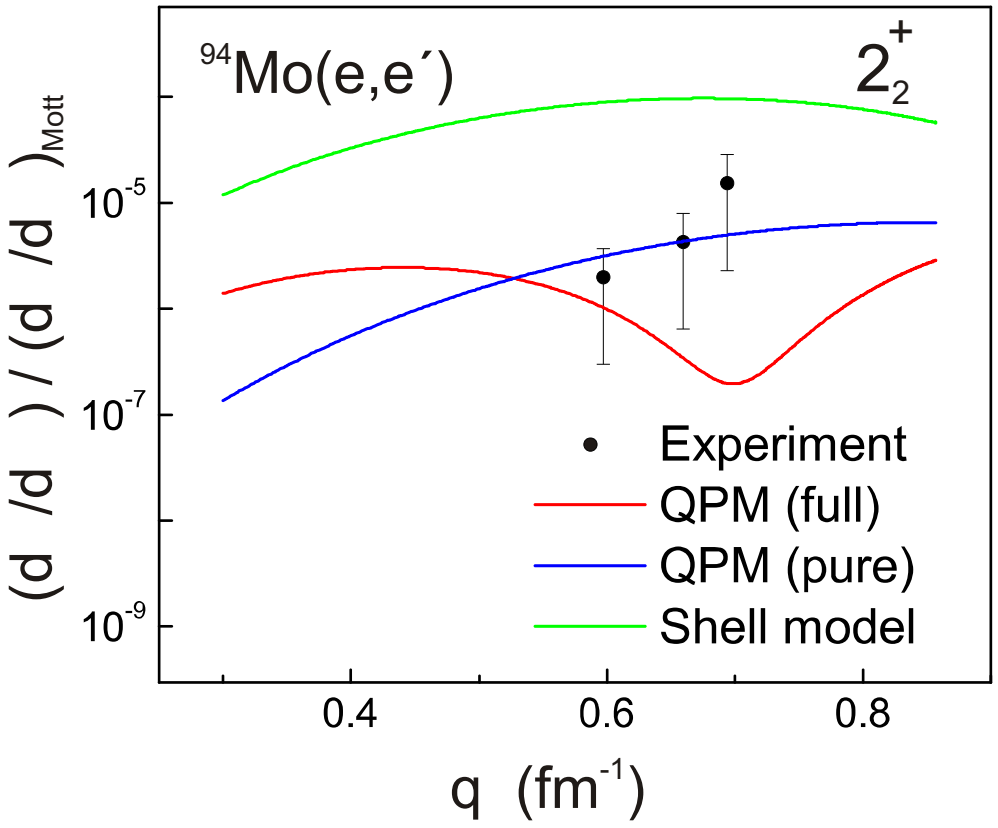


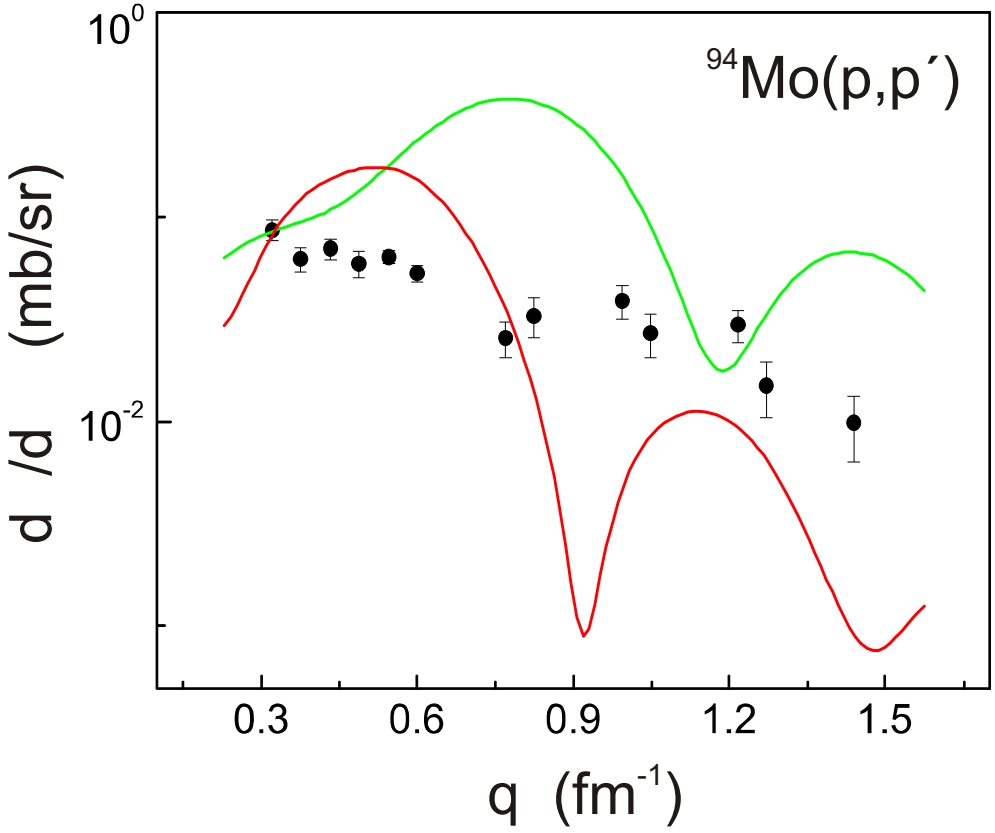
One-Phonon MS State





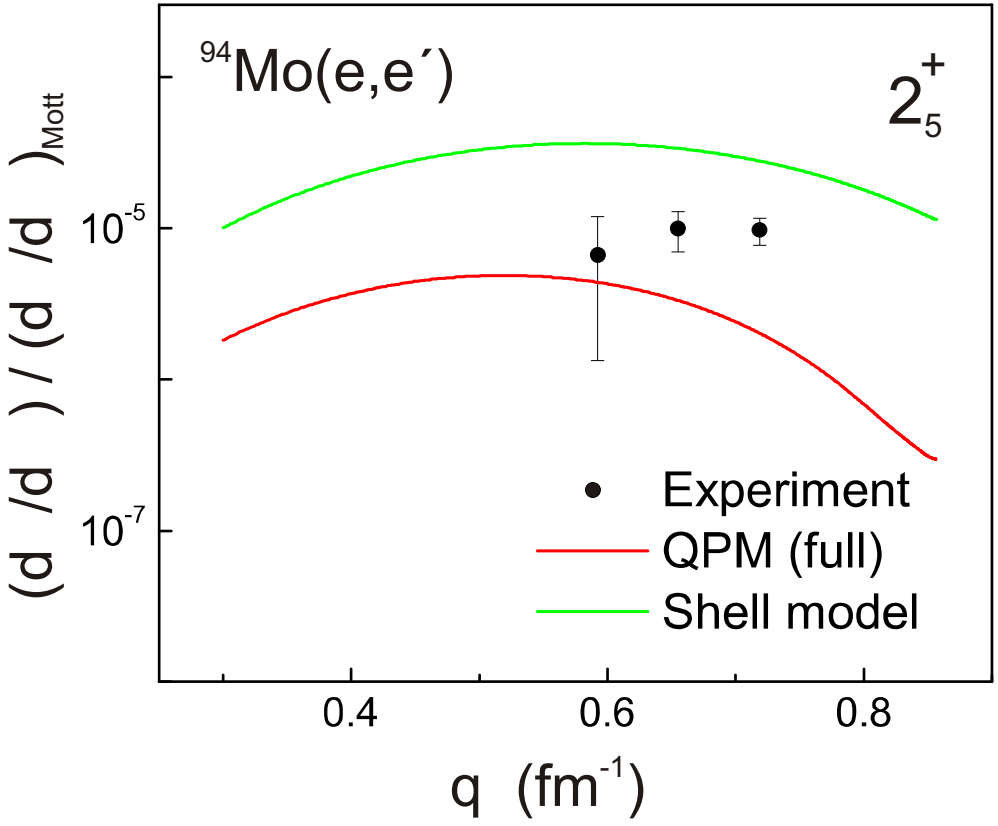
Two-Phonon Symmetric State

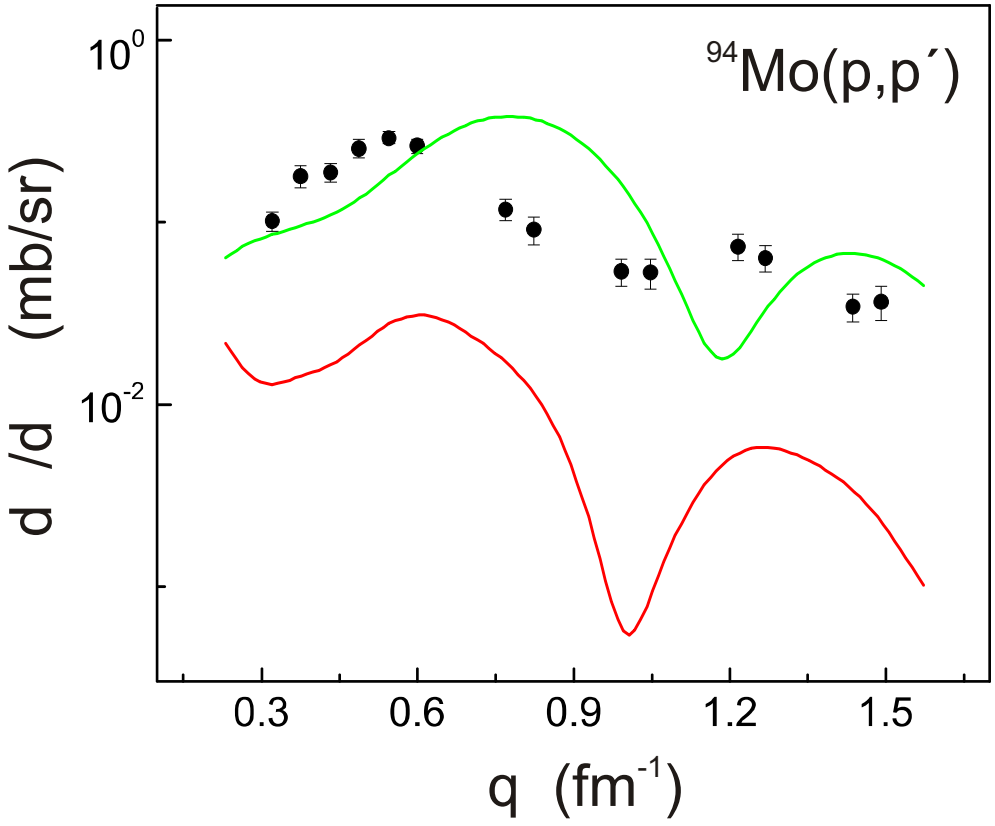




- pure two-phonon state
- two-step contributions?

Two-Phonon MS State





- 7-10% one-phonon admixture
- two-step contributions?

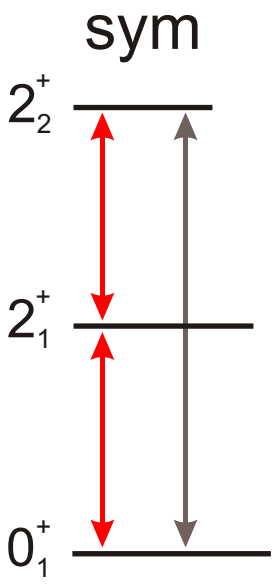
Coupled-Channel Analysis

- Collective model

$$\Rightarrow \quad U_{fi}(r) = -\frac{{}_{L}R_0}{2L+1}\frac{d}{dr}U(r), \qquad L \quad 2$$

$$\Rightarrow \quad {}^{2}_{L} = \left(\frac{d}{d}\right)^{exp}_{L} \Big/ \left(\frac{d}{d}\right)^{DWBA}_{L}$$

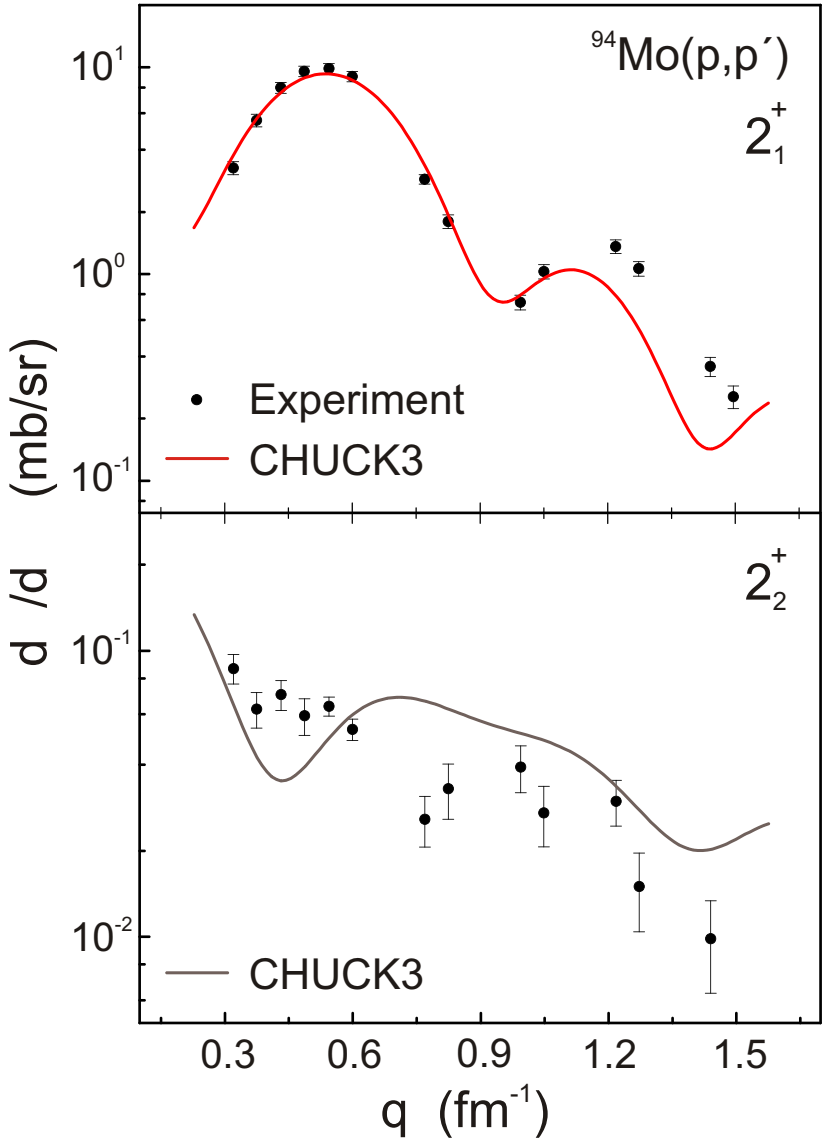
Coupled-Channel Analysis: One and Two-Phonon Symmetric States



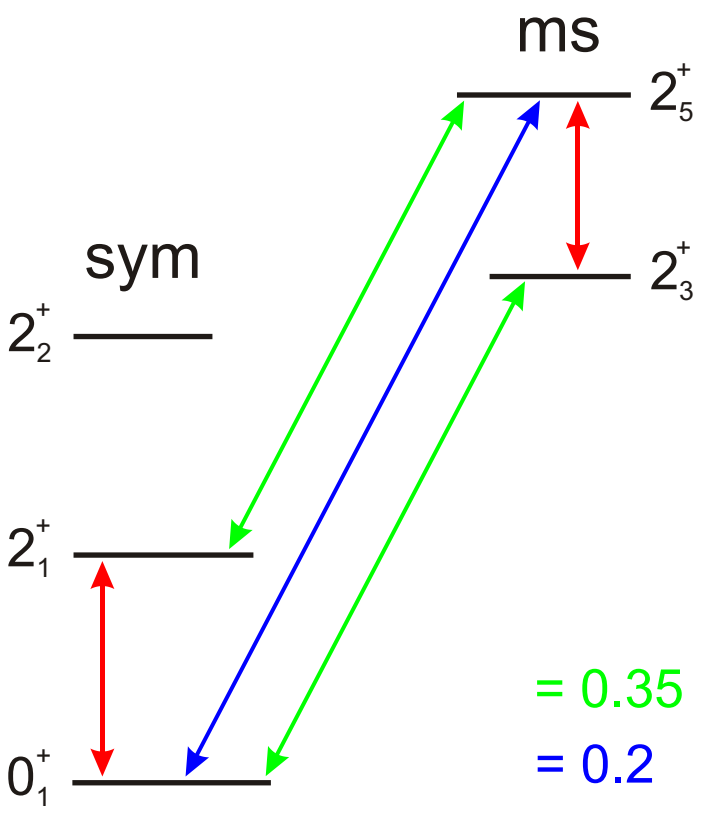
= 1.23

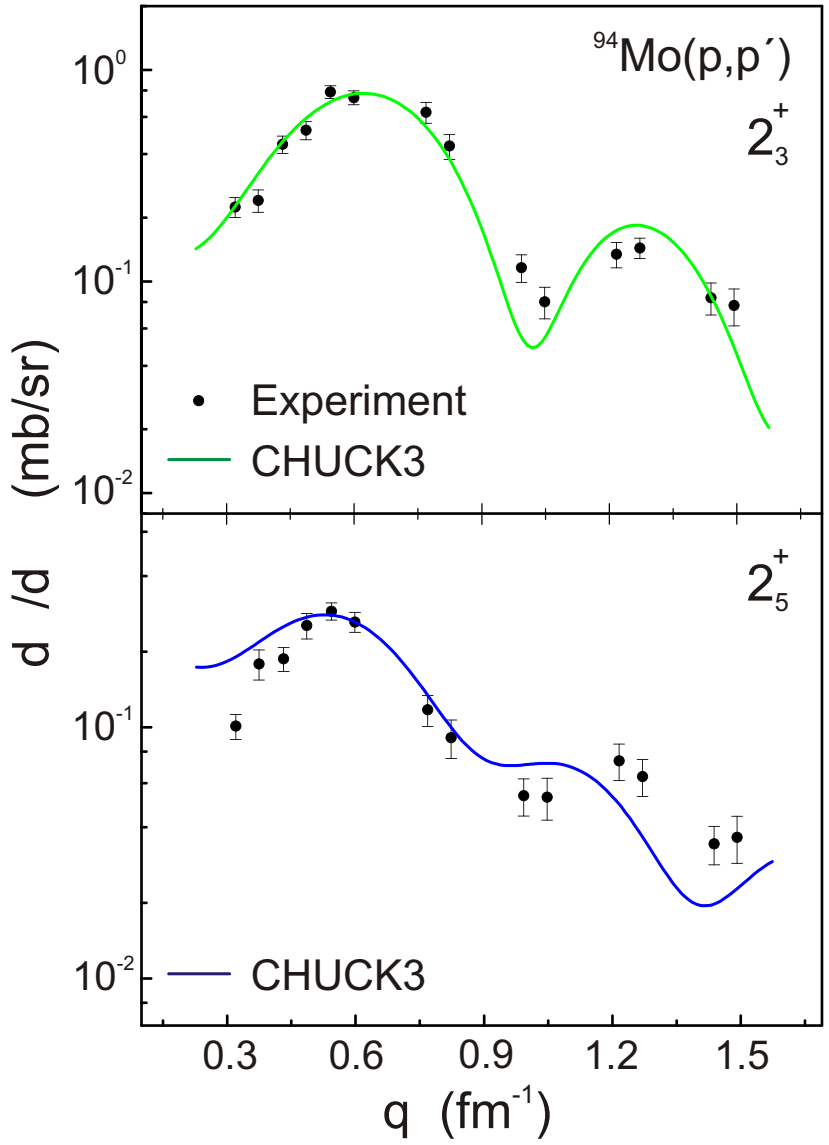
= 0.0

- pure two-phonon symmetric state confirmed



Coupled-Channel Analysis: One and Two-Phonon MS States





- one-phonon admixtures to two-phonon ms state confirmed

Summary

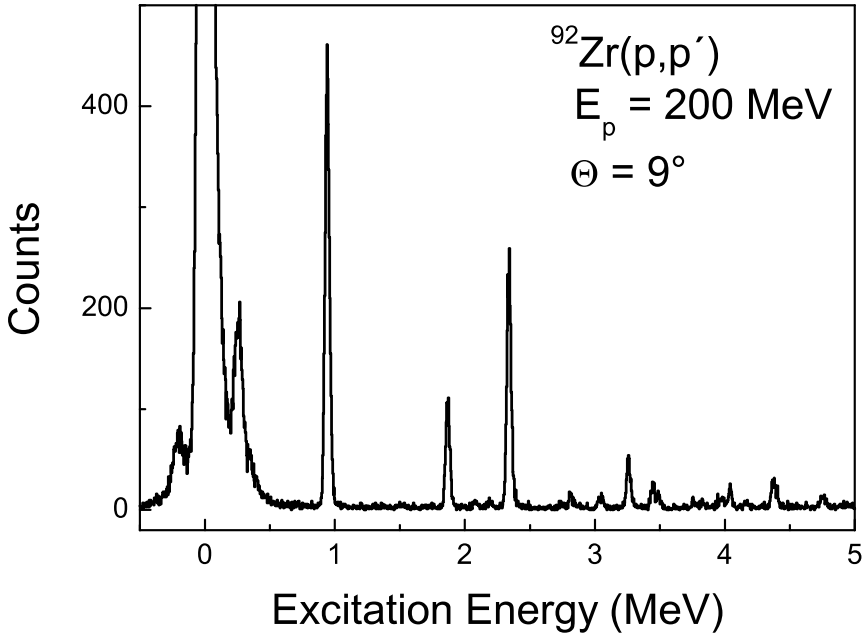
- Study of one- and two-phonon 2^+ states in ^{94}Mo with high-resolution (e,e´) and (p,p´) experiments
- Combined analysis with microscopic models reveals:
  - symmetric and ms character of one-phonon states
  - two-phonon symmetric state extremely pure
  - about 25% admixtures in the two-phonon ms wave function (mostly 3-phonon)
  - quantitatively consistent results after inclusion of two-step processes in (p,p´)

Outlook

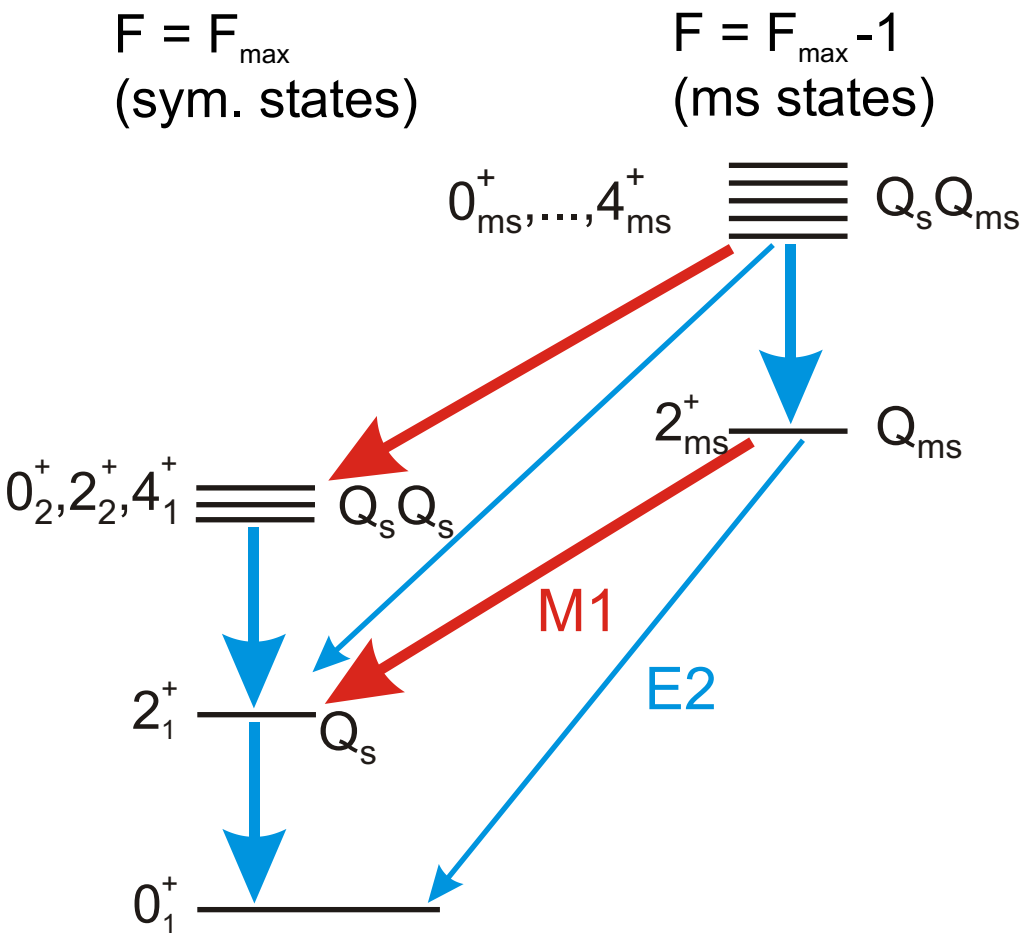
- The case of ^{92}Zr: Mixed-symmetry concept seems to fail
  C.Fransen *et al.,* Phys. Rev. C 71 (2005) 054304

⇒ Experiments:

- ☑ (p,p´) at iThemba LABS
- ☐ (e,e´) at S-DALINAC



Identification of Mixed-Symmetry States: Q-Phonon Scheme



- Strong **E2** transitions for decay of sym. Q-phonon
- Weak E2 transitions for decay of ms Q-phonon
- Strong **M1** transitions for decay of ms states to sym. states