Investigation of the mixed-symmetry states in ^{94}Mo by means of high-resolution electron and proton scattering*

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Content

- Motivation
- Experiments
- Results and microscopic interpretations
- Summary and outlook

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

- Pairing of nucleons to s-/ d-bosons

- F-Spin: boson: $F_0 = 1/2$
  boson: $F_0 = -1/2$

$$\frac{|N - N|}{2} \leq F \leq F_{max} = \frac{N + N}{2}$$

$F = F_{max}$: symmetric states

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

- Q-Phonon scheme: $Q_s = Q + Q$

$$|2_1^+\rangle \propto Q_s |0_1^+\rangle$$

$$Q_{ms} = \frac{N}{2}\left(\frac{Q}{N} - \frac{Q}{N}\right)$$

$$|2_{ms}^+\rangle \propto Q_{ms} |0_1^+\rangle$$

Identification of Mixed-Symmetry States: Q-Phonon Scheme

$F = F_{max}$ (sym. states)

$F = F_{max}-1$ (ms states)

$0^+_{ms},\ldots,4^+_{ms}$ ≡≡≡ $Q_s Q_{ms}$

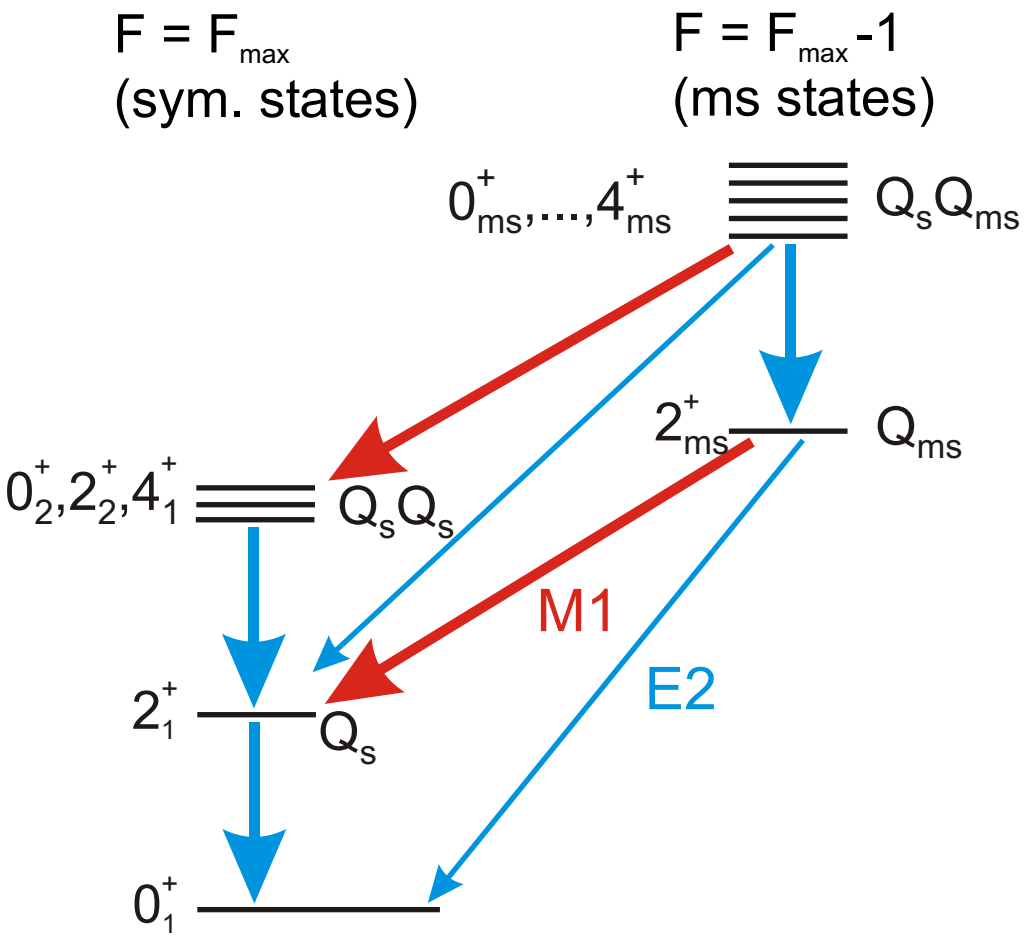
2^+_{ms} —— Q_{ms}

$0^+_2, 2^+_2, 4^+_1$ ≡≡≡ $Q_s Q_s$

2^+_1 —— Q_s

0^+_1 ————

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

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

Why (e,e´) and (p,p´) Experiments?

- 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

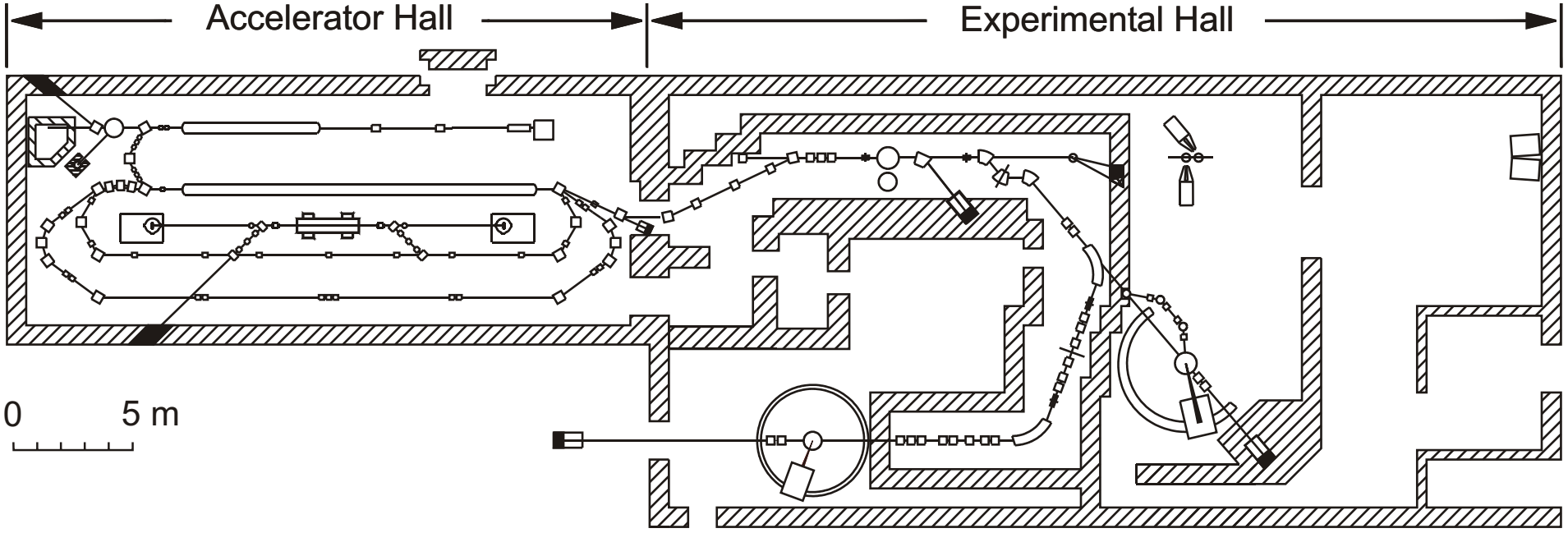
Identification of Mixed-Symmetry States: Experiments

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

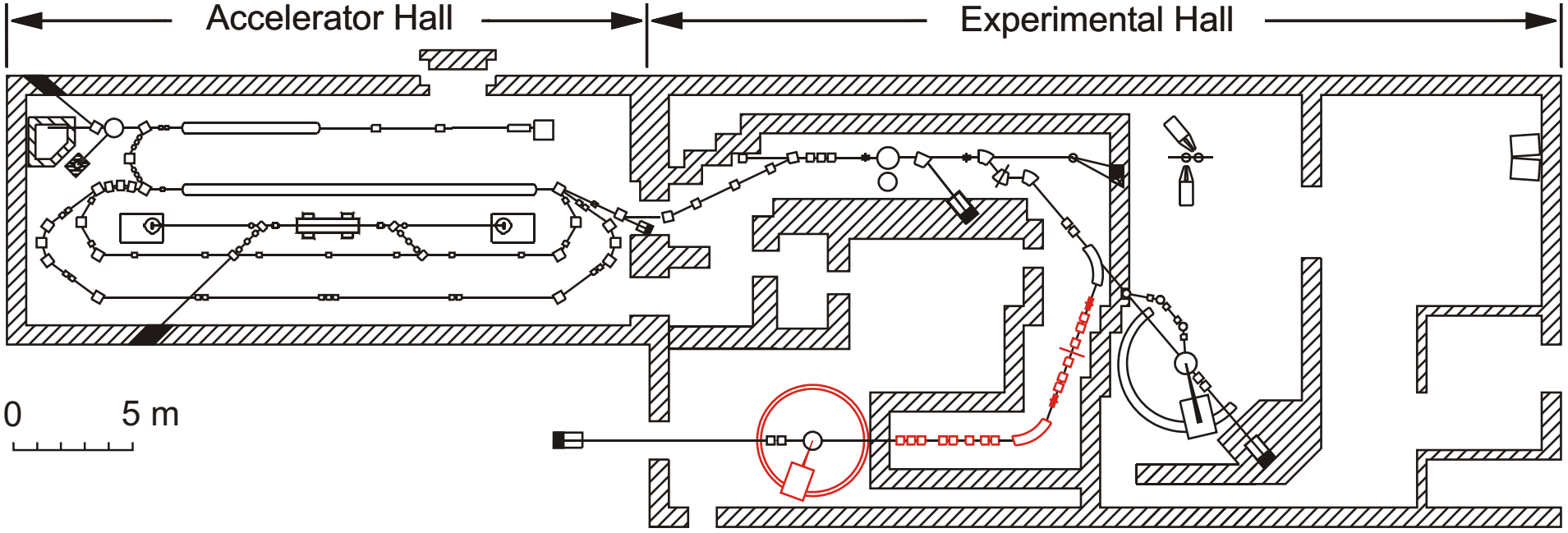
  E_e = 70 MeV
  = 93°- 165°
  E = 30 keV (FWHM)
- (p,p´):
  SSC, iThemba LABS

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

S-DALINAC



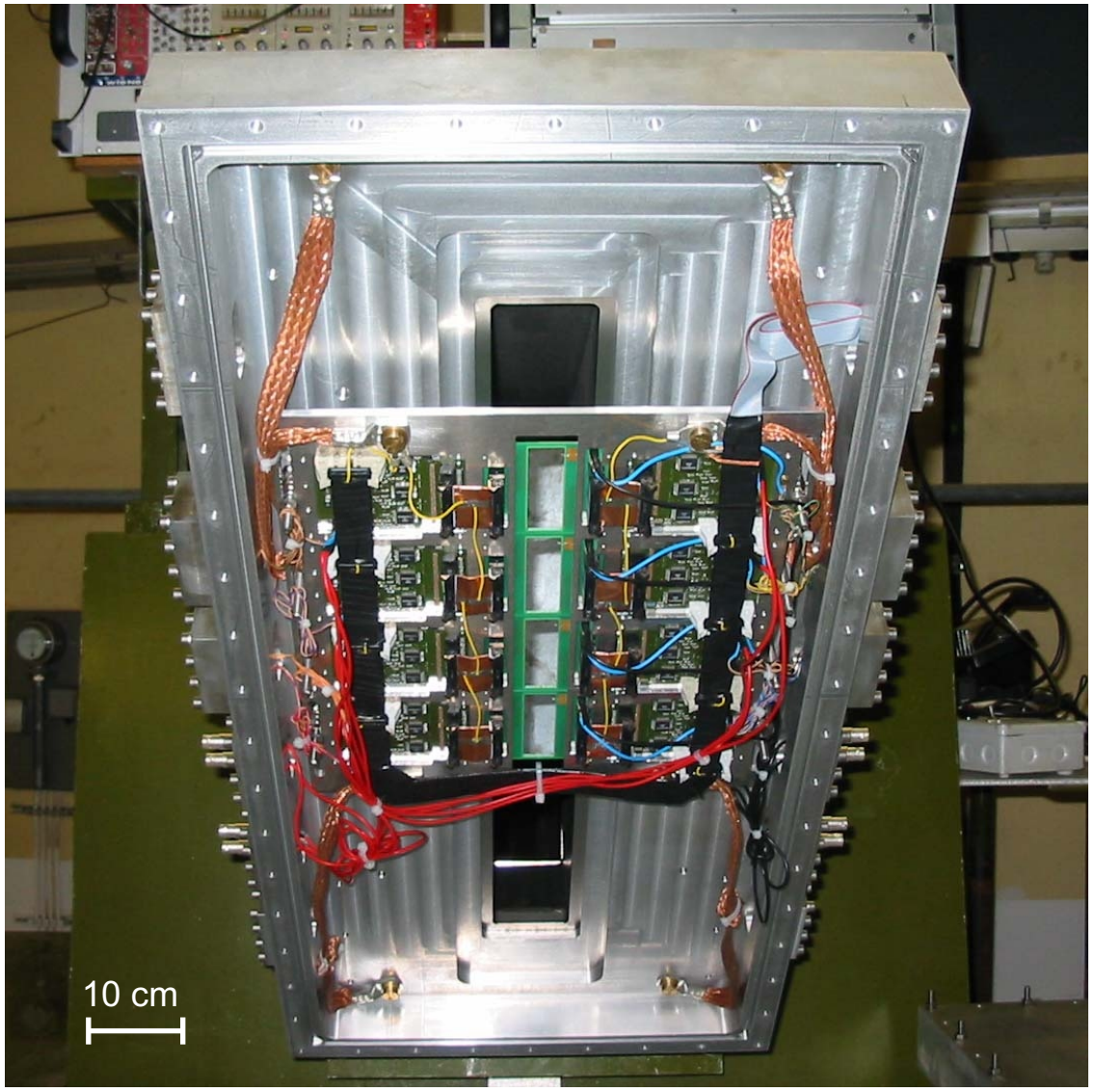
S-DALINAC



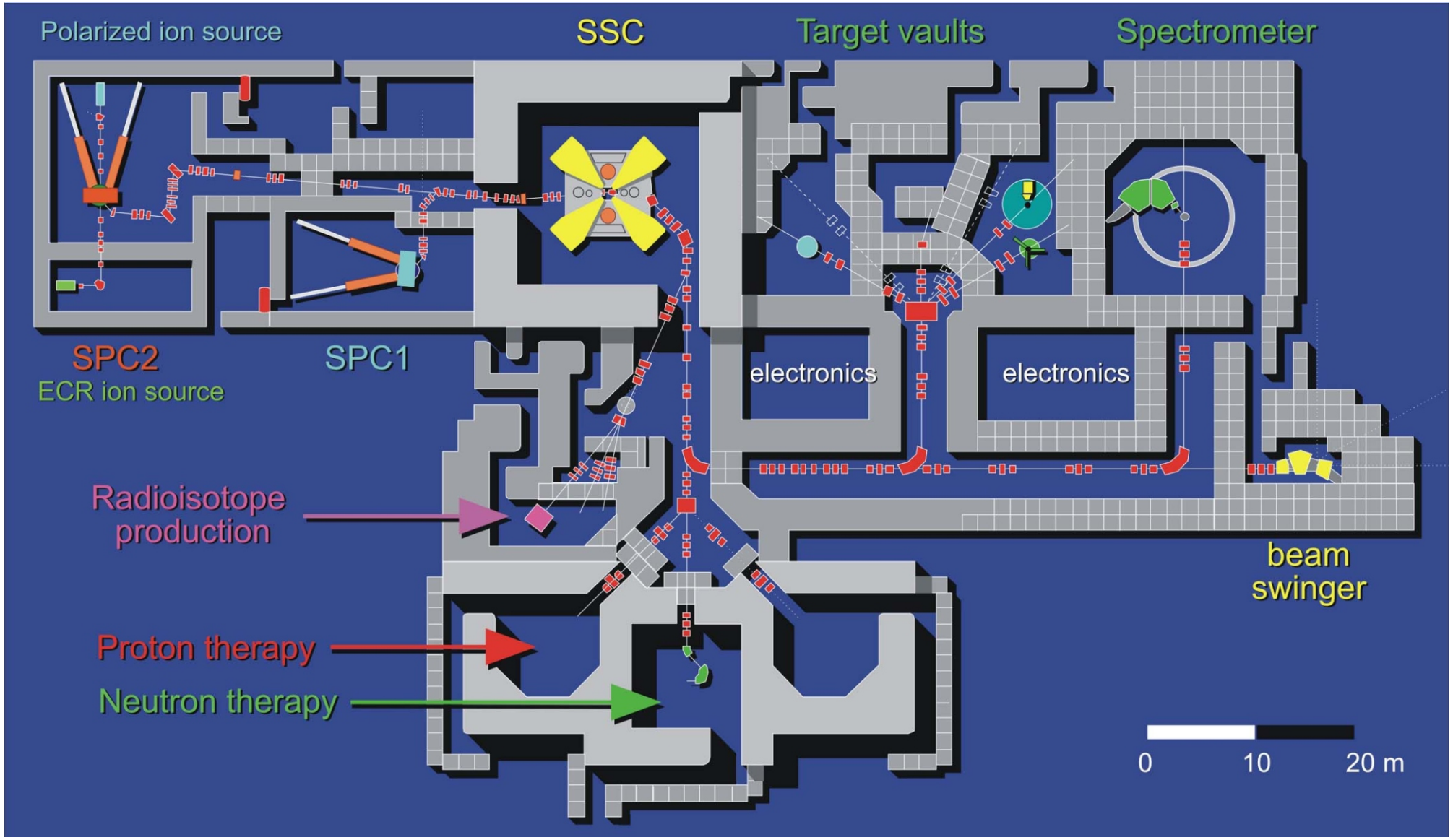
- High-resolution (e,e´) experiments

LINTOTT Spectrometer

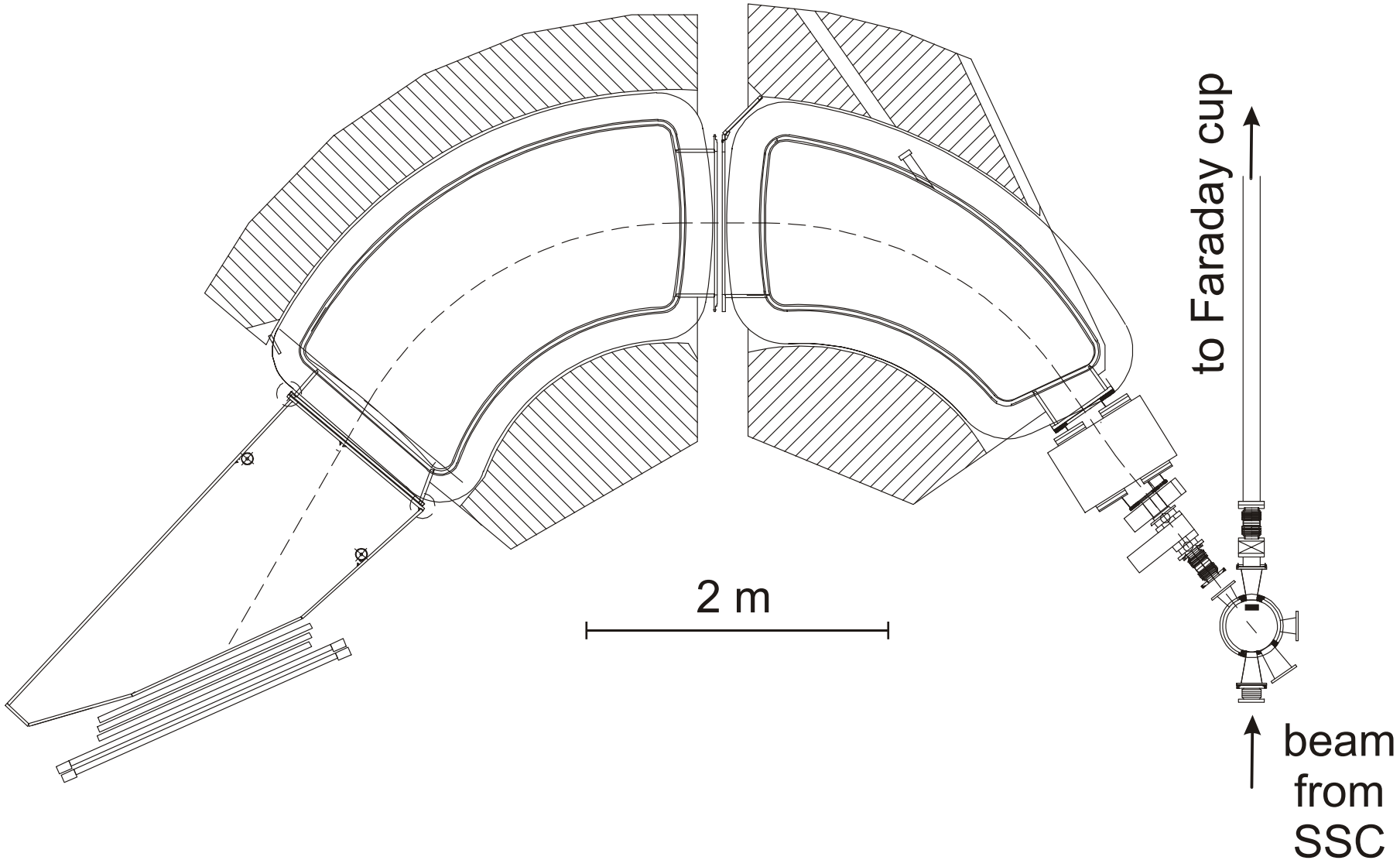
Focal Plane Detector System: Si Microstrip Detectors



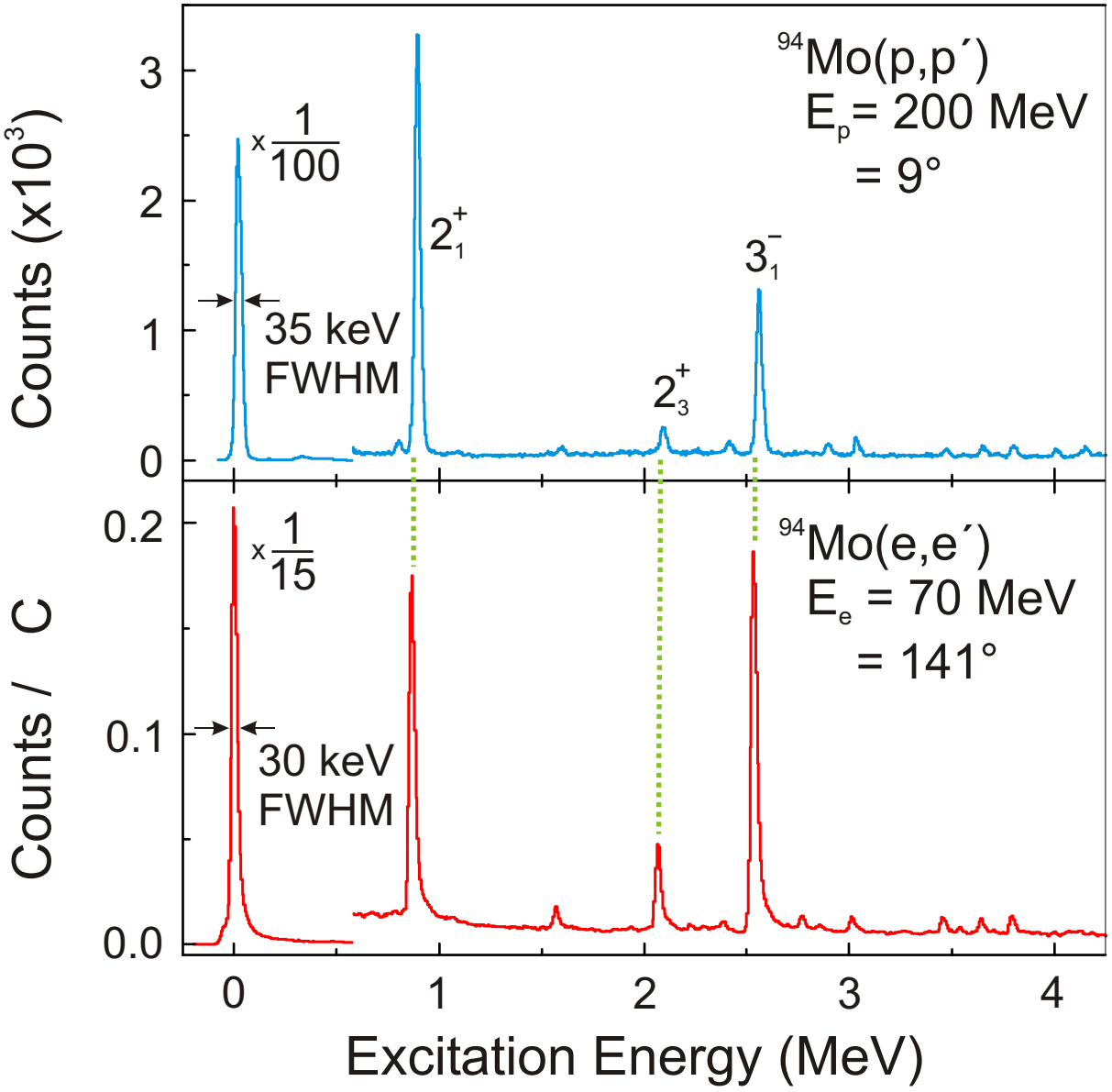
Separated-Sector Cyclotron Facility



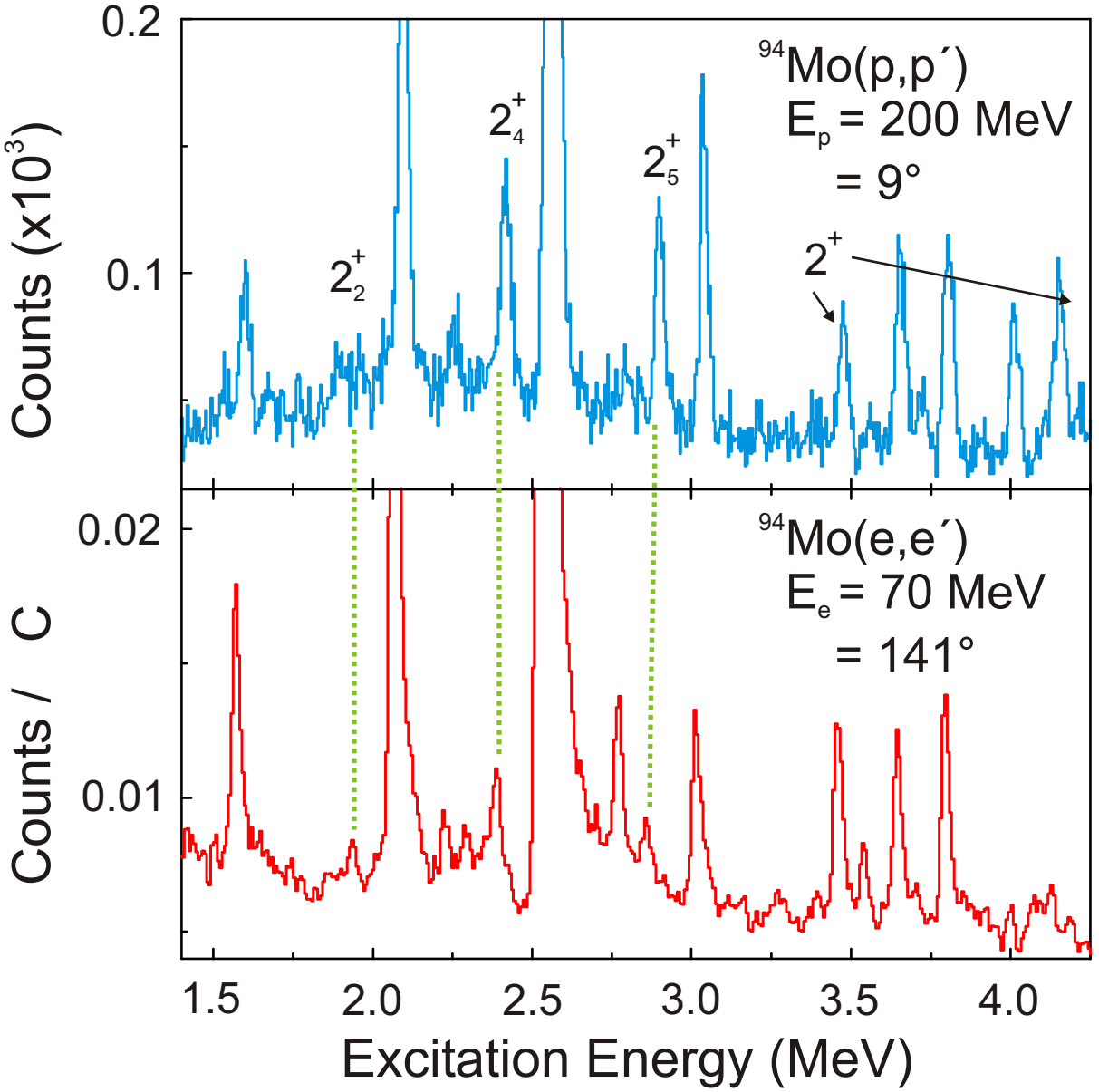
K600 Magnetic Spectrometer at iThemba LABS



Measured Spectra



Measured Spectra



Theoretical Calculation

- Quasi-Particle Phonon Model (QPM)
  - ⇒ full (up to 3 phonons)
  - ⇒ pure one- and two-phonon states

- Shell Model (SM)
  - ⇒ ^{88}Sr core
  - ⇒ Surface Delta Interaction (SDI)

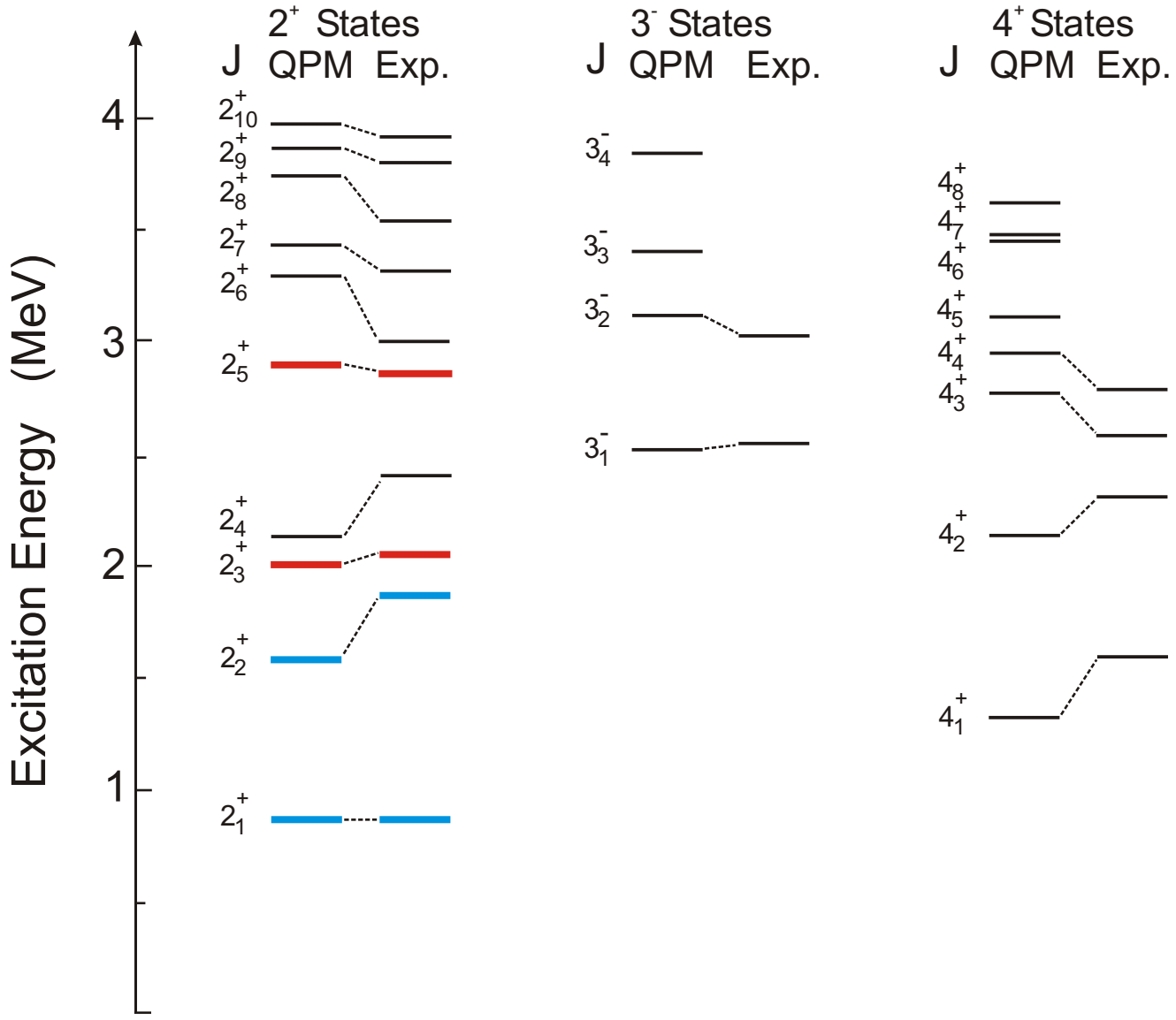
Theoretical Calculation

- IBA-2 Model
  - ⇒ SM wave function for s and d boson pairs
  - ⇒ p and n separately
  - ⇒ transition densities:

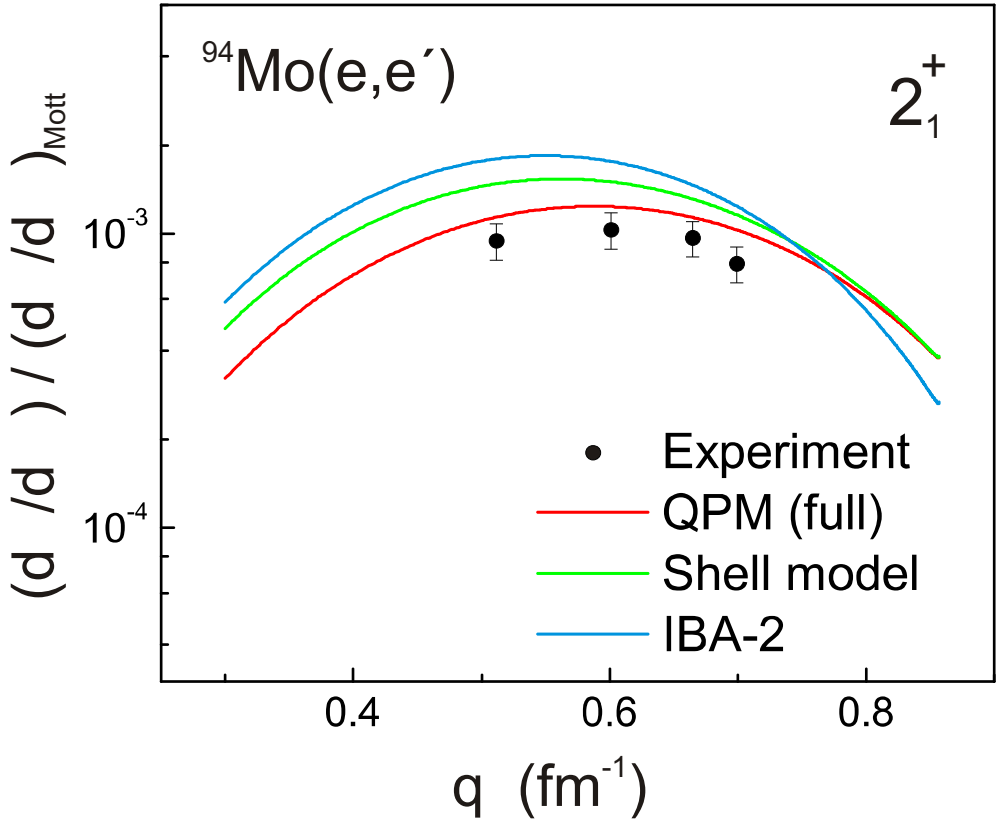
$$= \sum_{i}^{IBA} \left({}^{WS}_{s.p.} + {}^{Tassie}_{col} \right)$$

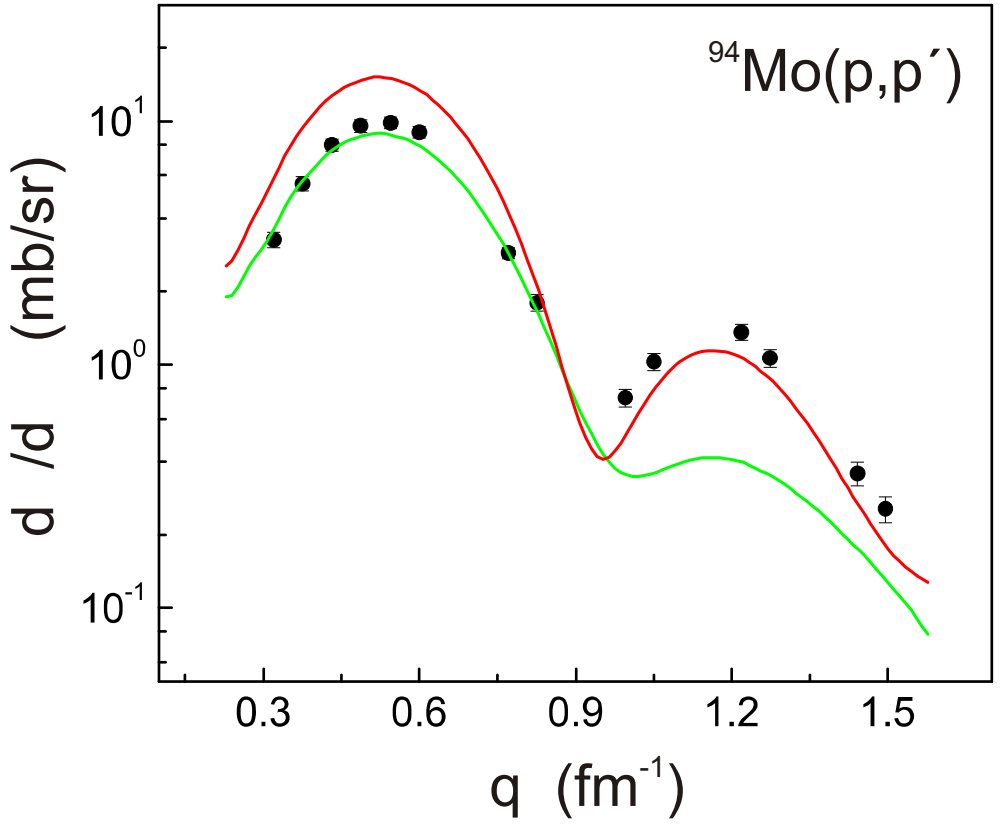
- Cross Sections
  - ⇒ DWBA treatment
  - ⇒ effective nucleon-target interaction (Paris, Love-Franey)

Experiment vs. QPM Predictions

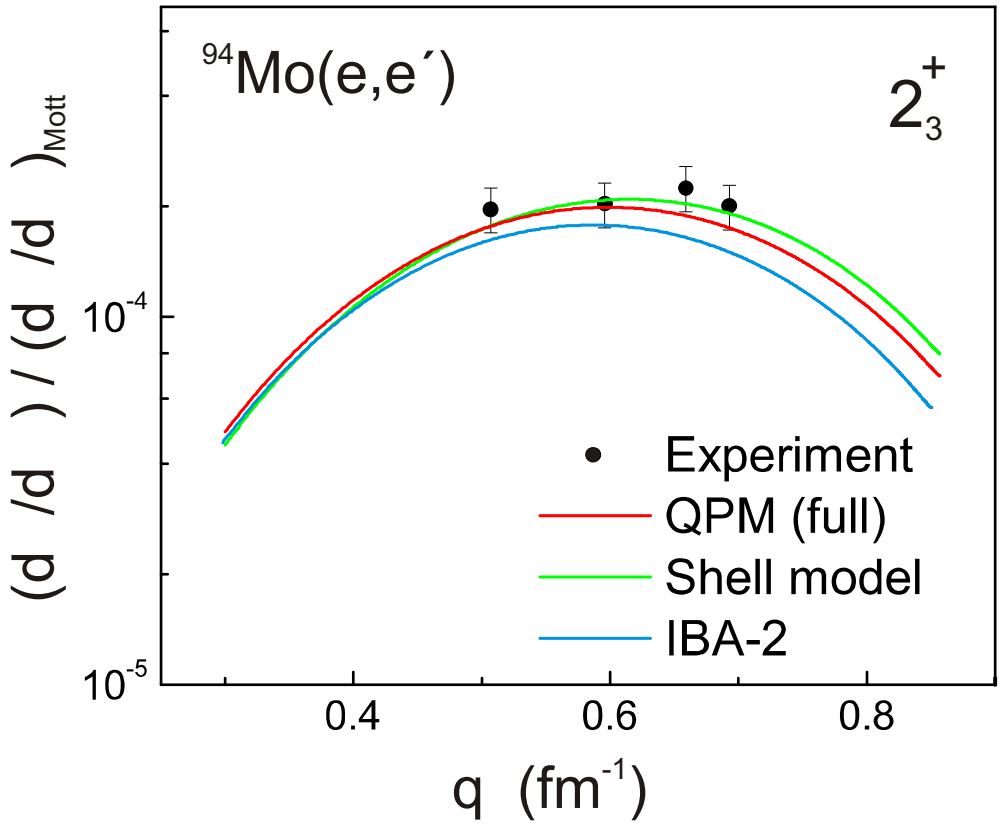


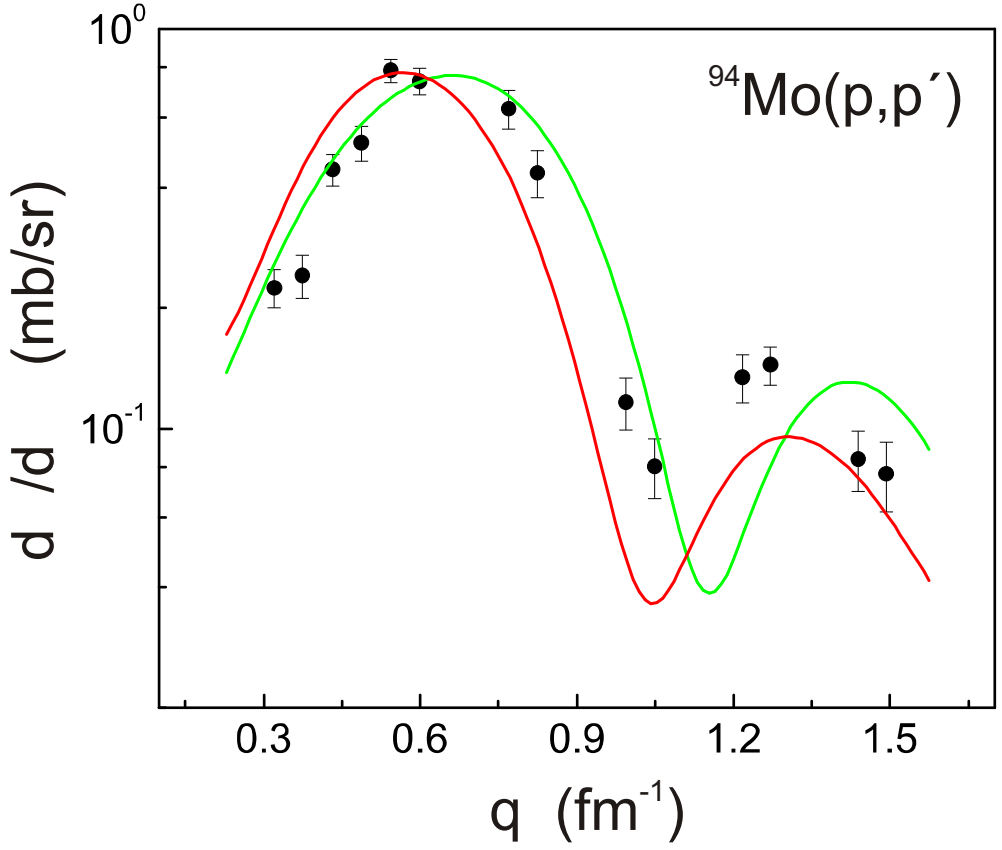
One-Phonon Symmetric State



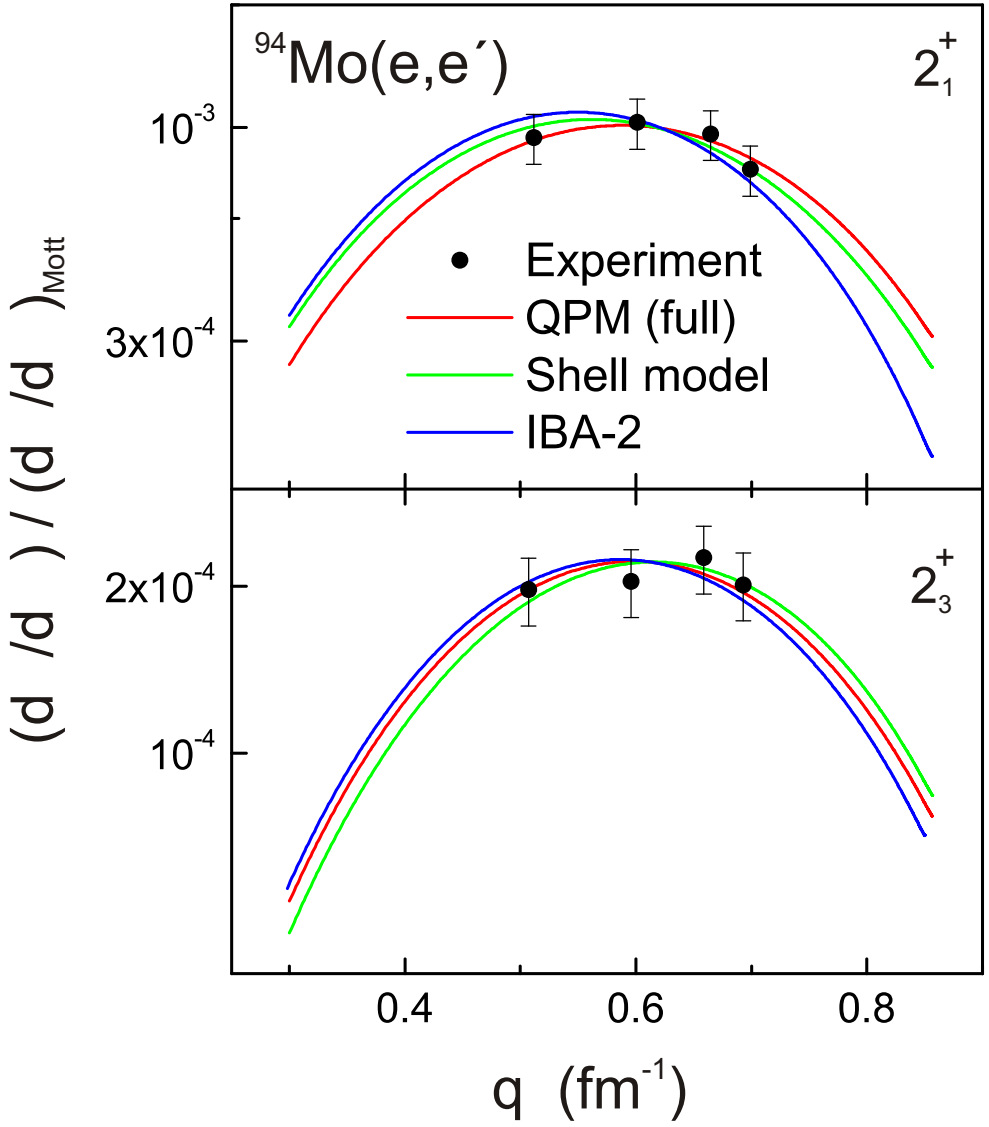


One-Phonon MS State





One-Phonon Symmetric and MS States: Momentum Transfer dependence



Model	$B(E2)\uparrow$
QPM	0.33
SM	0.48
IBA-2	1.56

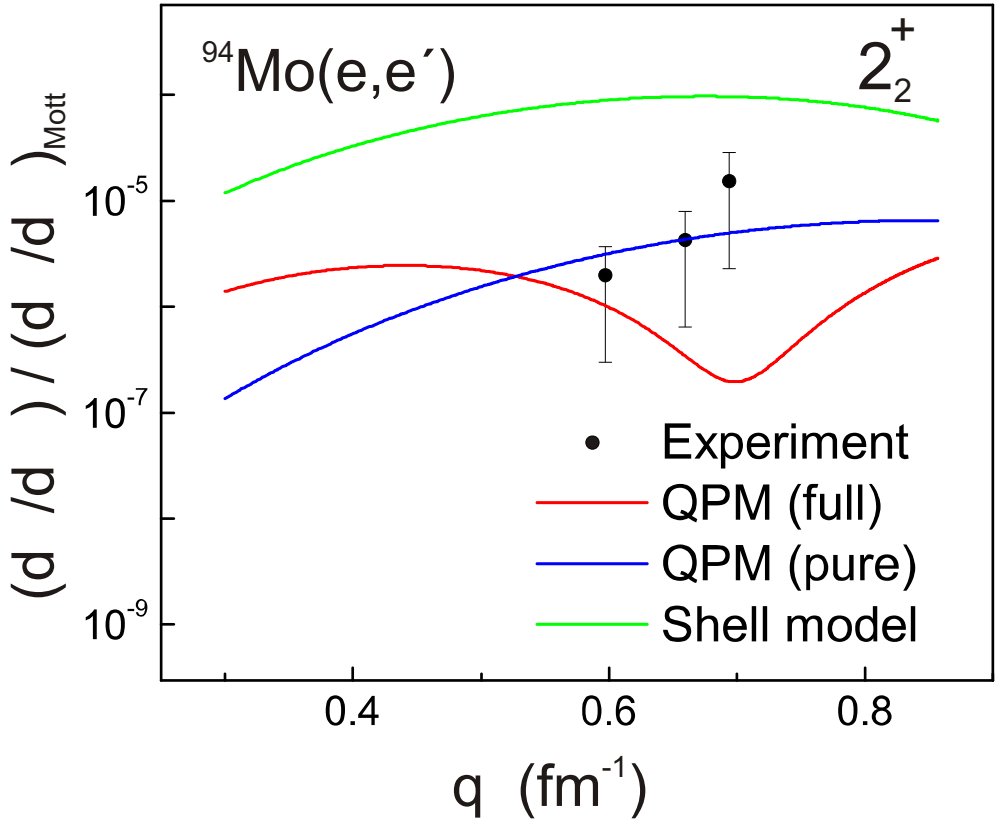
Model	$B(E2)\uparrow$
QPM	0.65
SM	0.53
IBA-2	1.05

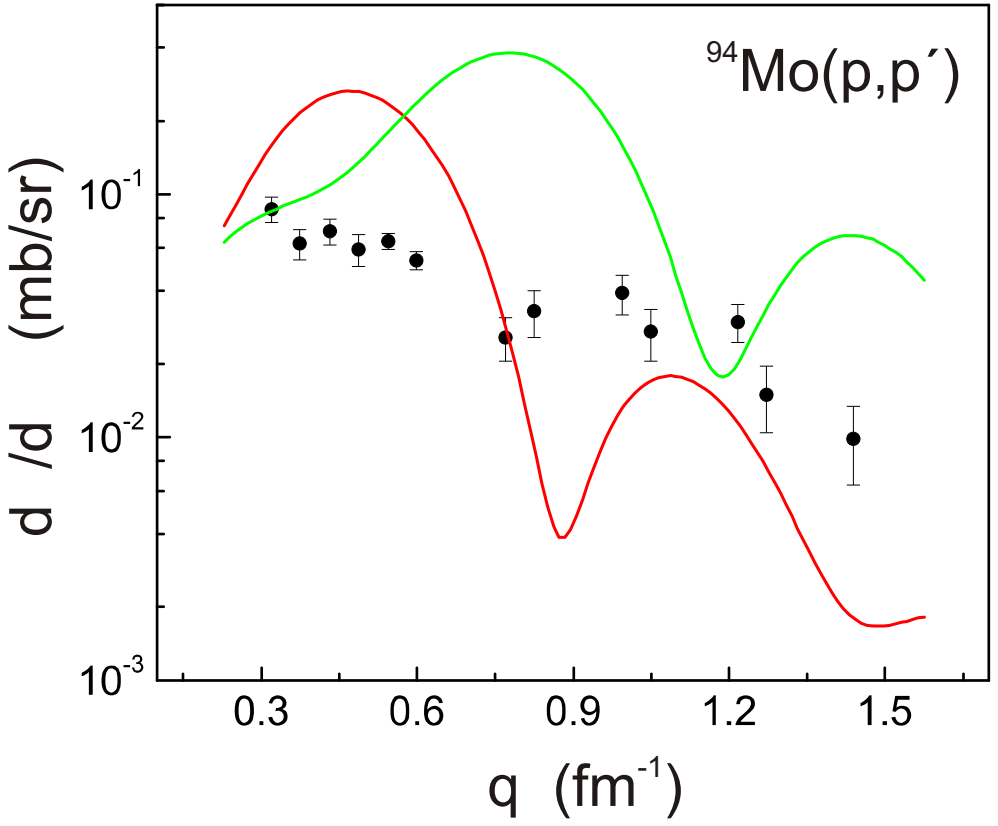
QPM Predictions: Wave Functions of One-Phonon Symmetric and MS States

Main config.	$2^+_{1,sym}$		$2^+_{3,ms}$	
	QPM	SM	QPM	SM
$(1g_{9/2}\ 1g_{9/2})$	0.66	0.54	0.64	0.43
$(2d_{5/2}\ 2d_{5/2})$	0.72	0.36	-0.71	-0.25

- symmetric state - isoscalar
- ms state - isovector

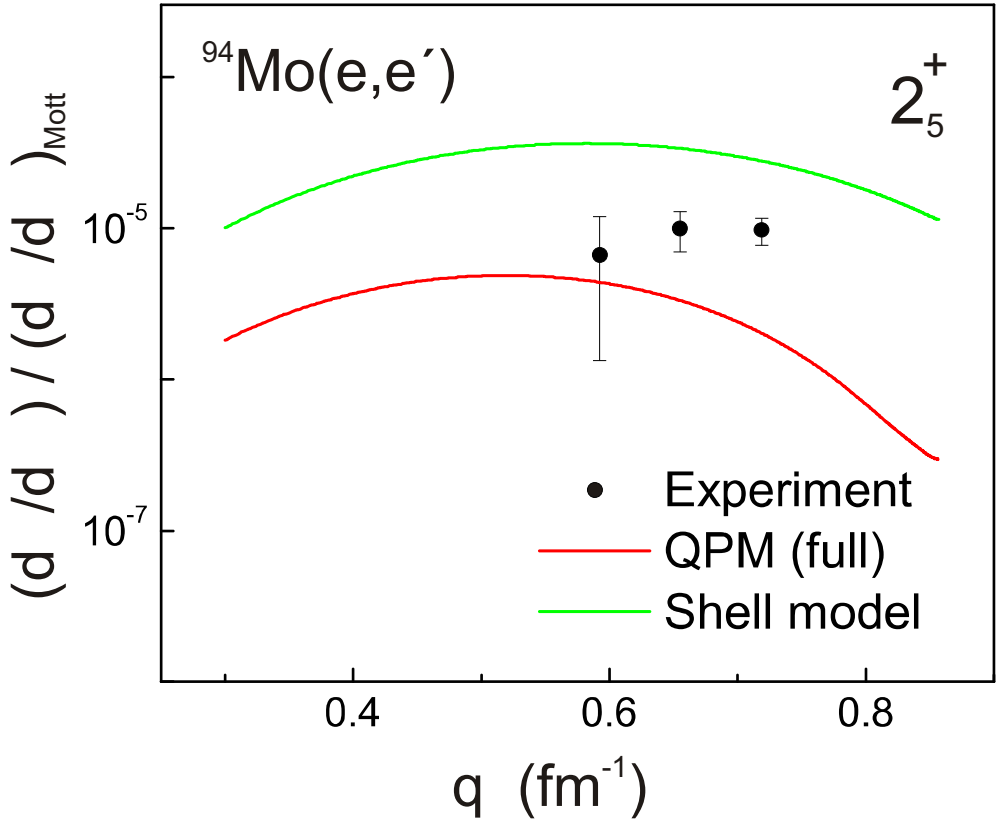
Two-Phonon Symmetric State

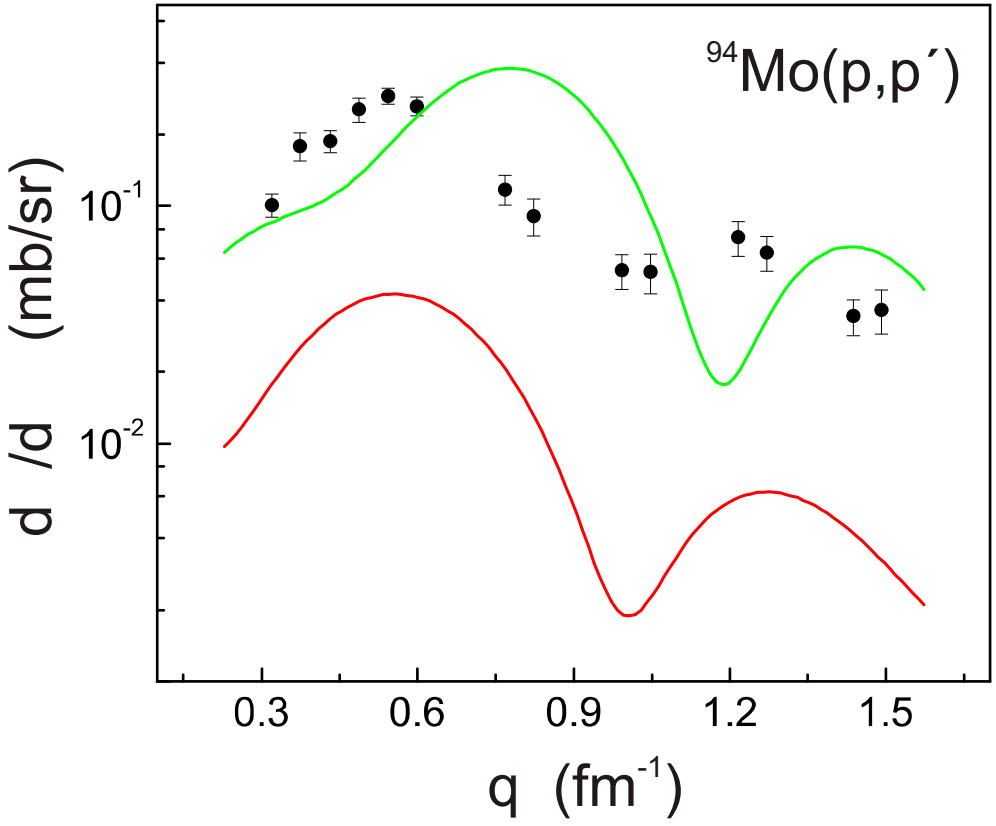




- pure two-phonon state

Two-Phonon MS State





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

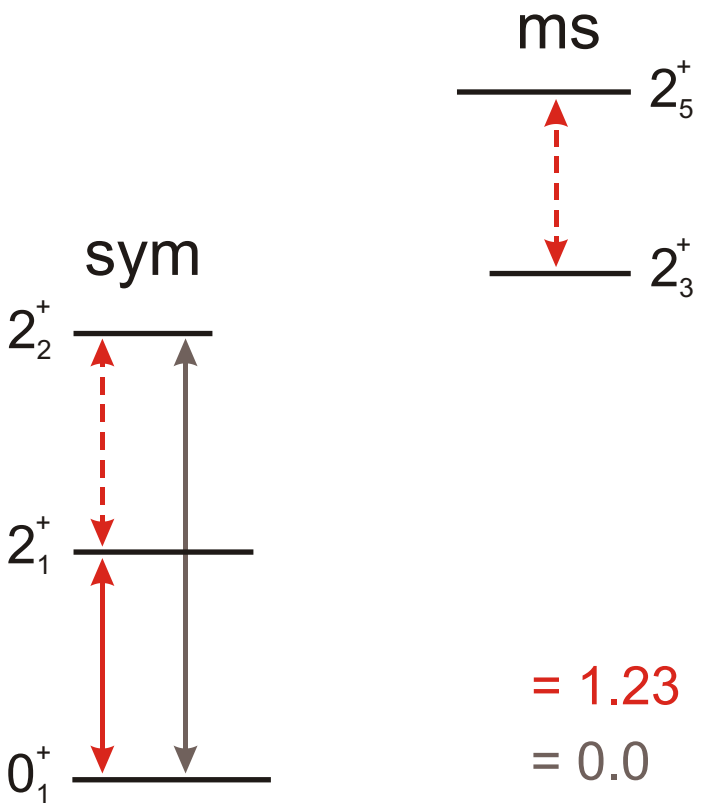
Coupled-Channel Analysis

- Collective model

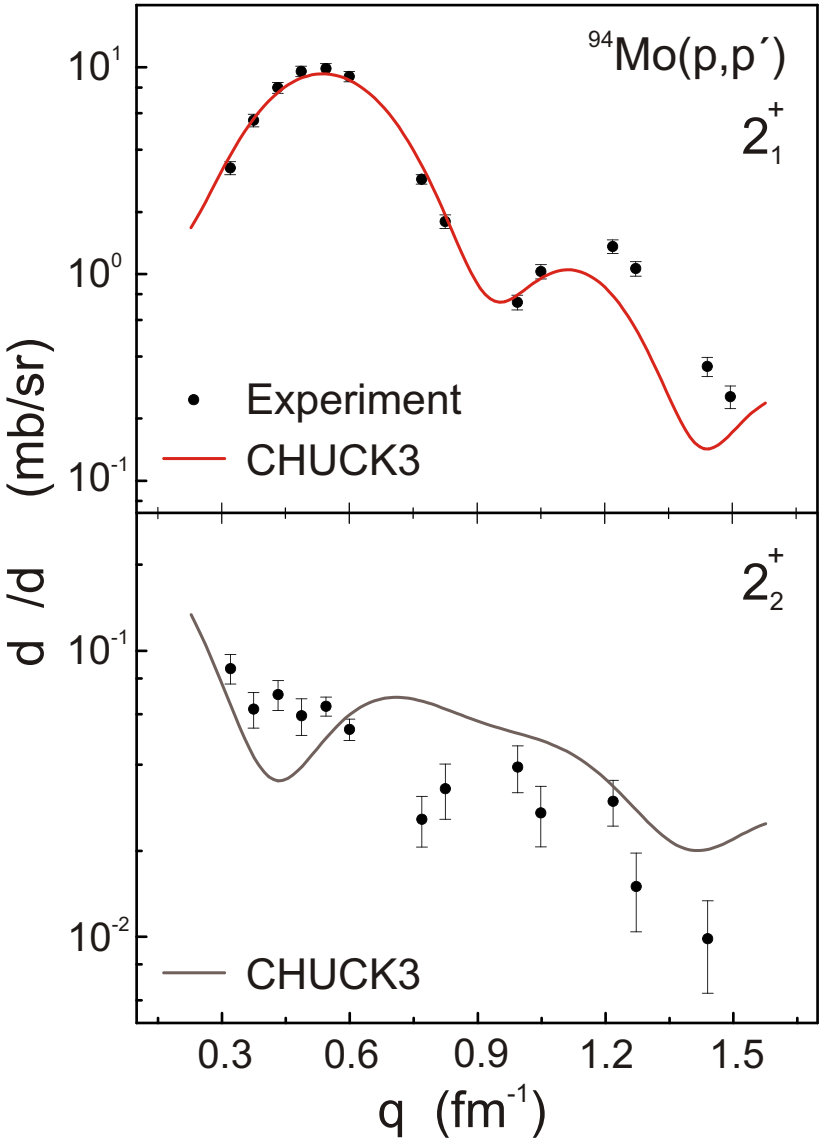
$$\Rightarrow \quad U_{fi}(r) = -\frac{{}^{L}R_0}{2L+1}\frac{d}{dr}U(r), \qquad L \geq 2$$

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

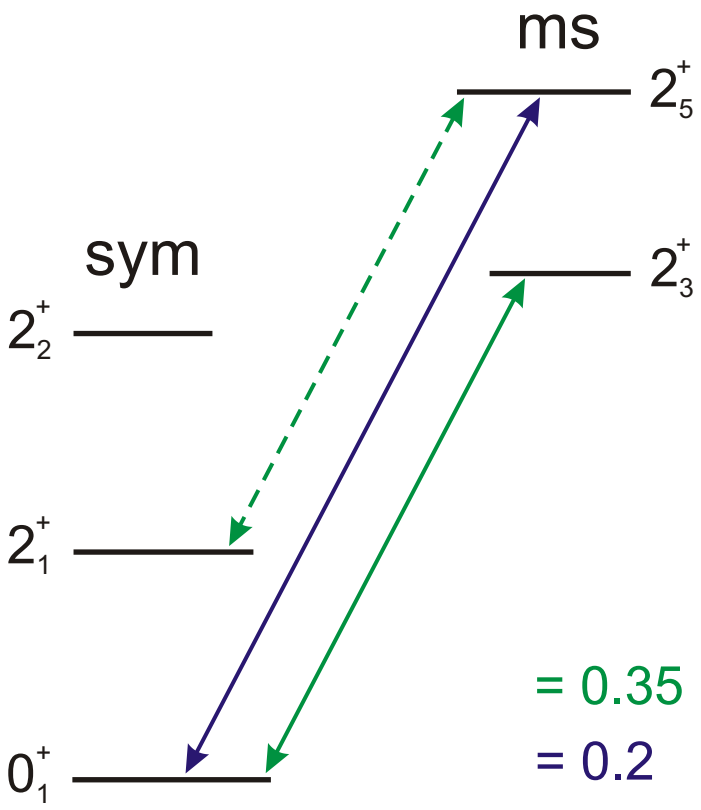
Coupled-Channel Analysis: One and Two-Phonon Symmetric States



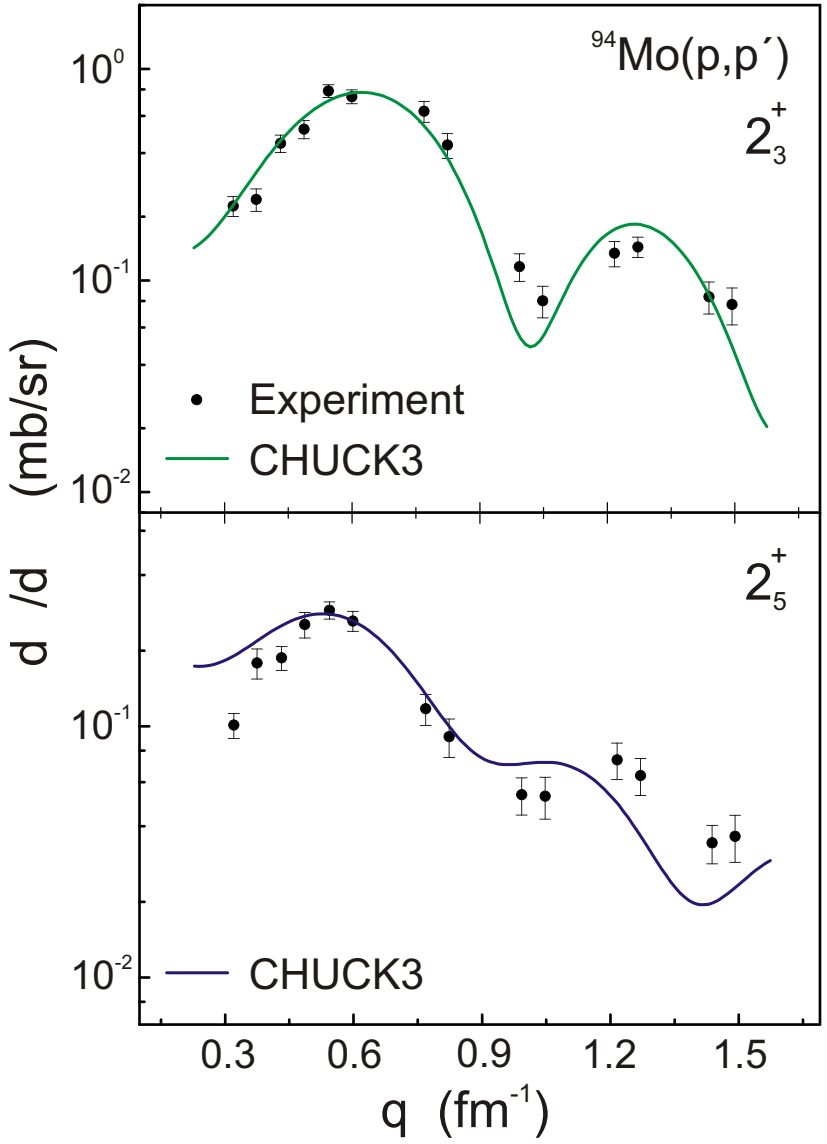
- pure two-phonon symmetric state confirmed



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



- admixture 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 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

- Systematic study around N=50 shell closure
- 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

- Other shell closures?