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Canada's national laboratory
for particle and nuclear physics
and accelerator-based science

Single Particle Structure of Exotic Sr Isotopes

Friday 15th July 2016

Steffen Cruz

UBC and TRIUMF

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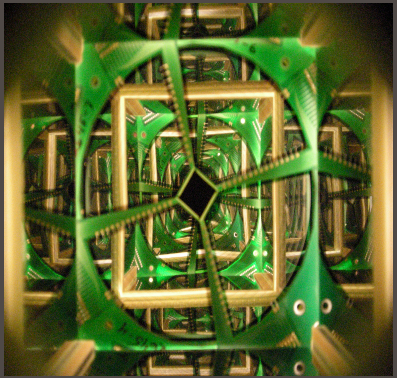
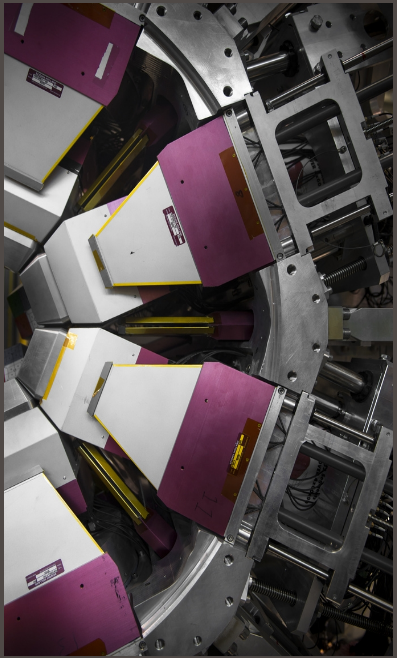
- Single Particle Configurations
- Shape Coexistence
- ^{95}Sr(d,p) Experiment
- Interpretation of Results

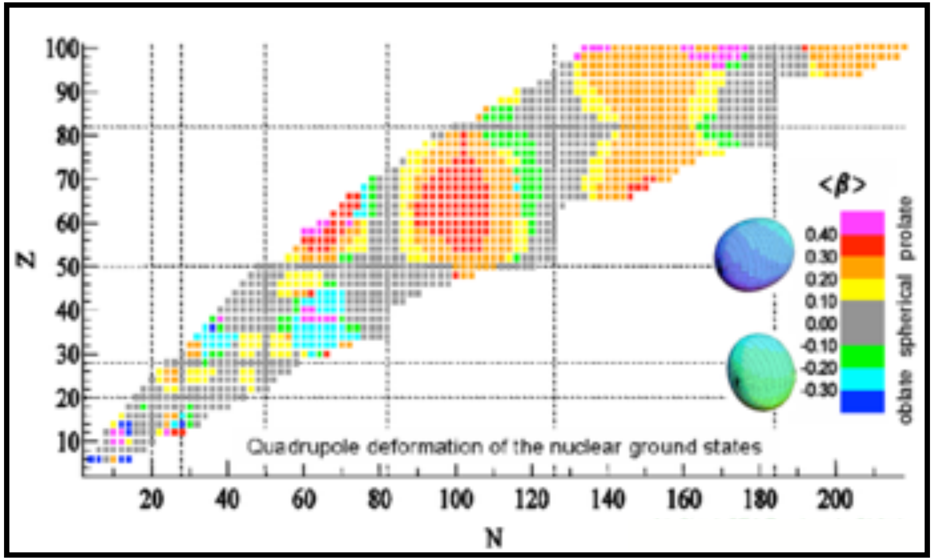




Quadrupole Deformation in Nuclei

- Shape deformation enables the nucleus to minimize its energy.
- HFB calculation (left) shows expected quadrupole deformation across nuclear chart.

Quadrupole deformation is a measure of nuclear shape.



Plot source: M. Girod, CEA

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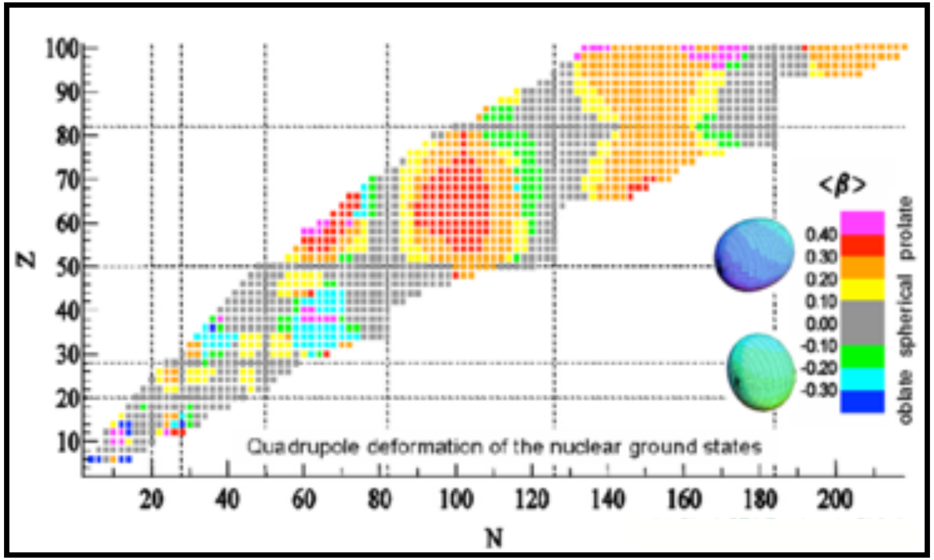

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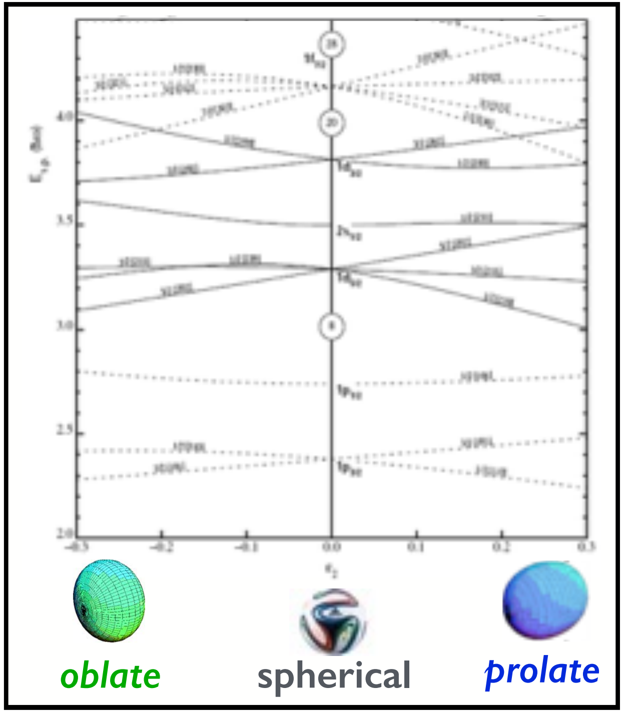
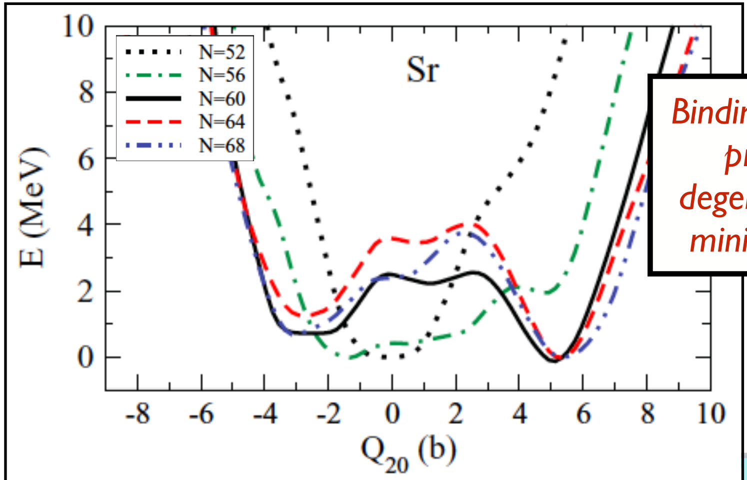
Nilsson model: Different deformations have different single particle configurations



Plot source: R.F. Casten

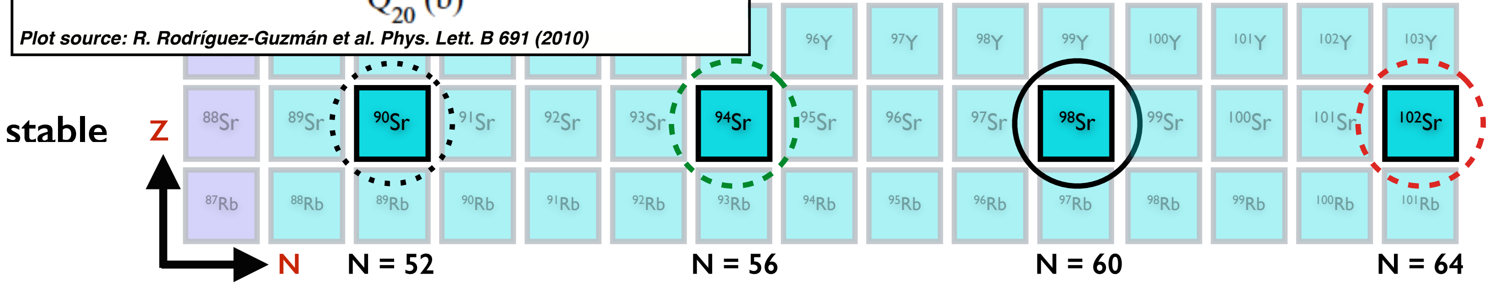
Shape Coexistence at Z~40 N~60

- State of the art (beyond mean field) calculations predict binding energy as a function of deformation.
- Measurements of single particle levels in ^{95,96,97}Sr essential for a detailed description of this transitional region.



Plot source: R. Rodríguez-Guzmán et al. Phys. Lett. B 691 (2010)

Binding energy curves predict almost degenerate potential minima at N = 60.



neutron drip line A>107

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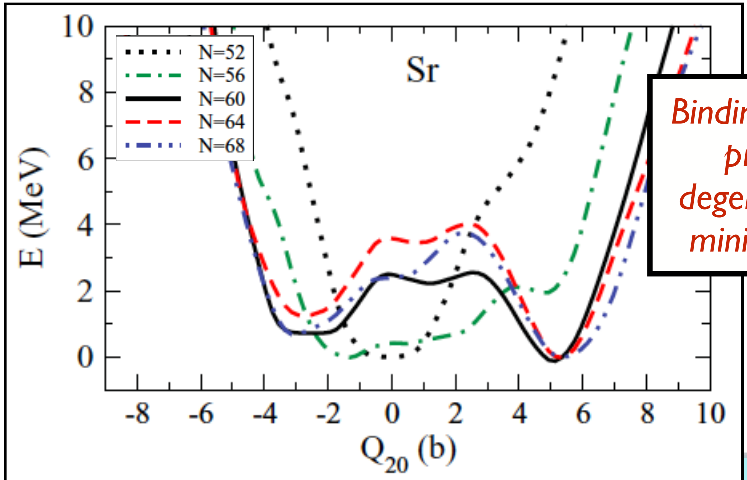

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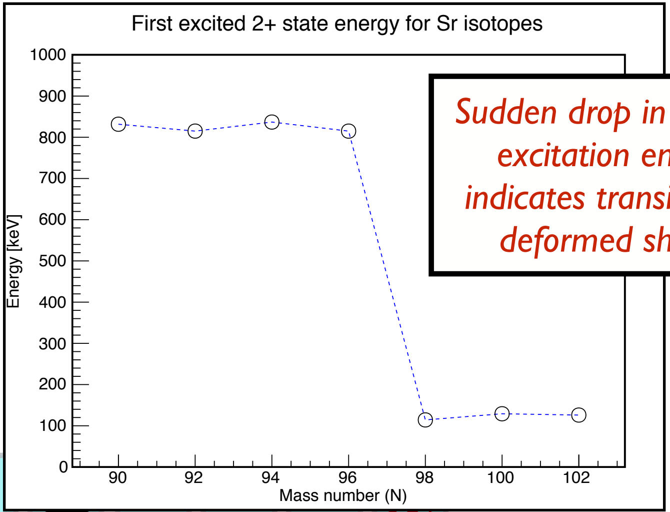
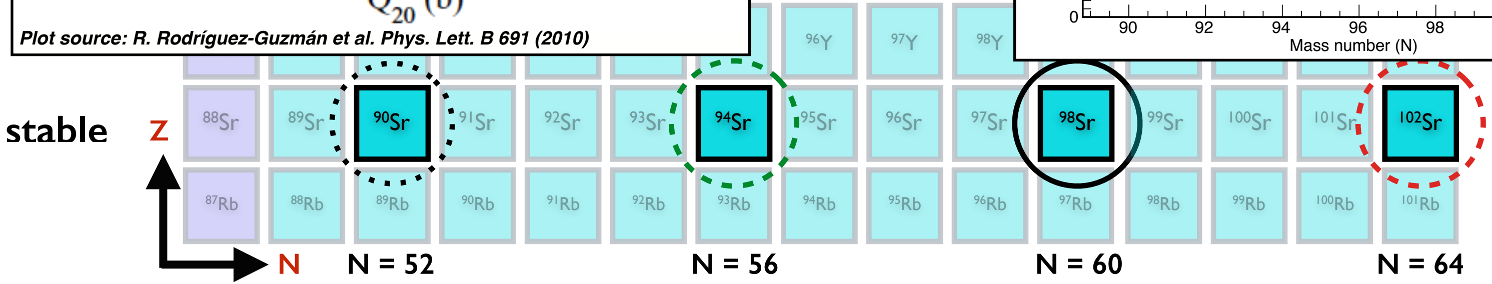


Sudden drop in first 2^+ excitation energy indicates transition to deformed shape



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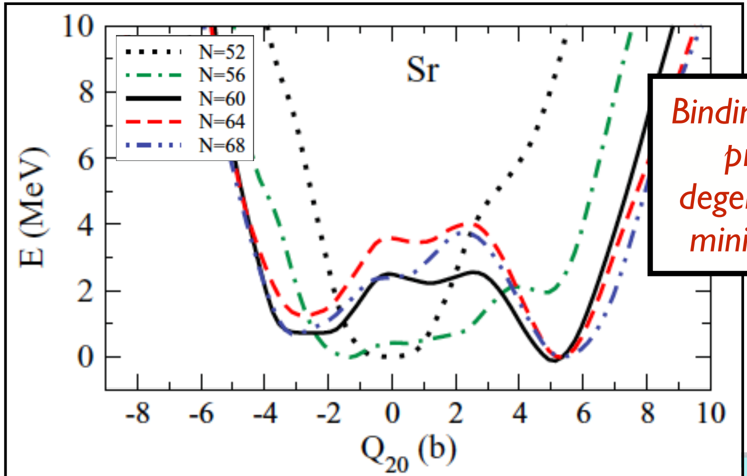

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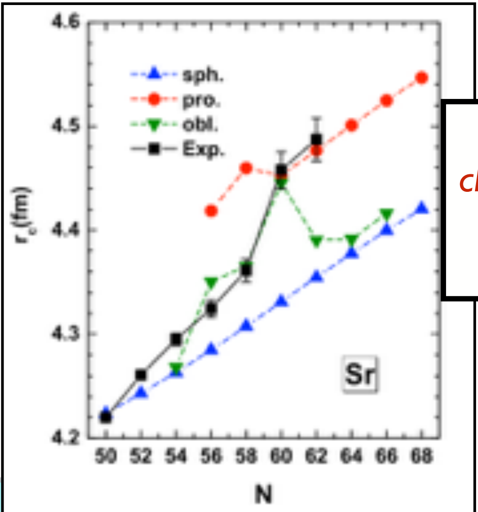
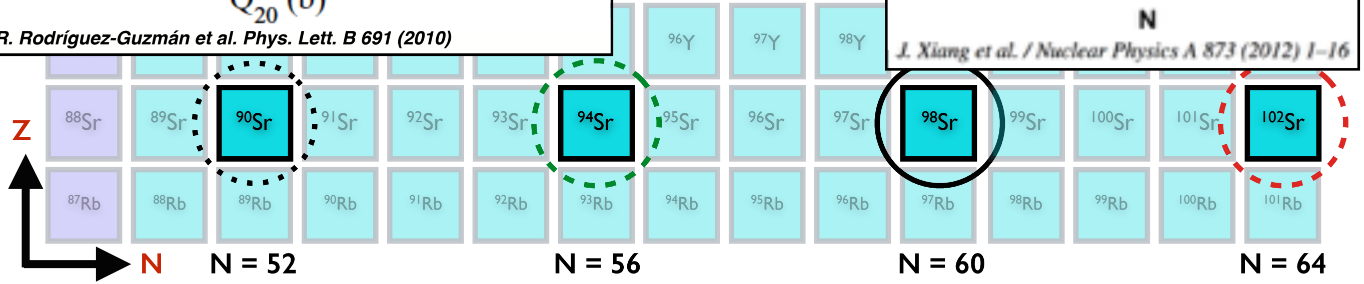


J. Xiang et al. / Nuclear Physics A 873 (2012) 1–16

Sudden increase in charge radius suggests change of ground state shape

stable



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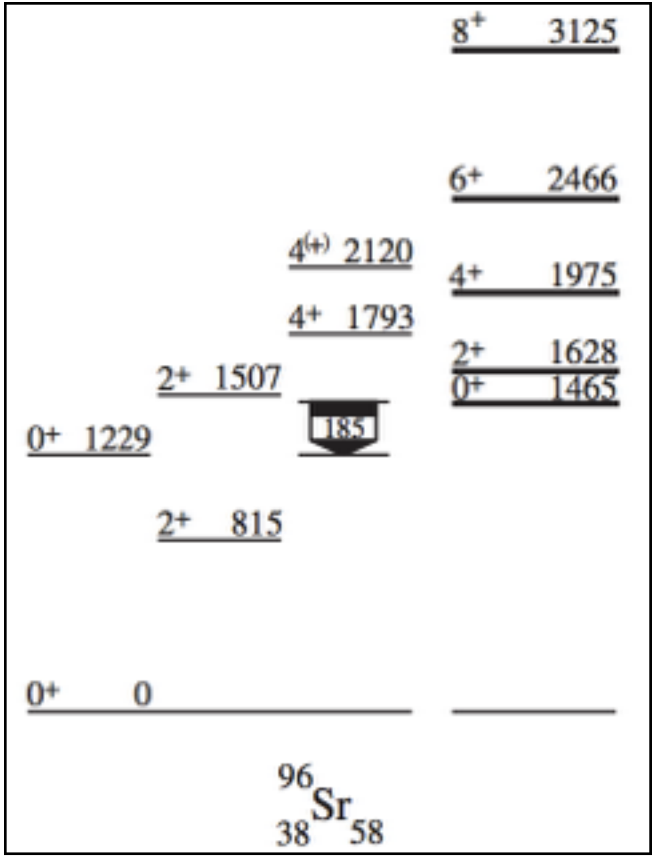
Shape Coexistence at Z~40 N~60

- The strong 0_3^+ (1465 keV) $\rightarrow 0_2^+$ (1229 keV) E0 transition is characteristic of coexisting shapes.



Shape coexistence in atomic nuclei [Rev. Mod. Phys. 83, 1467 (2011)]

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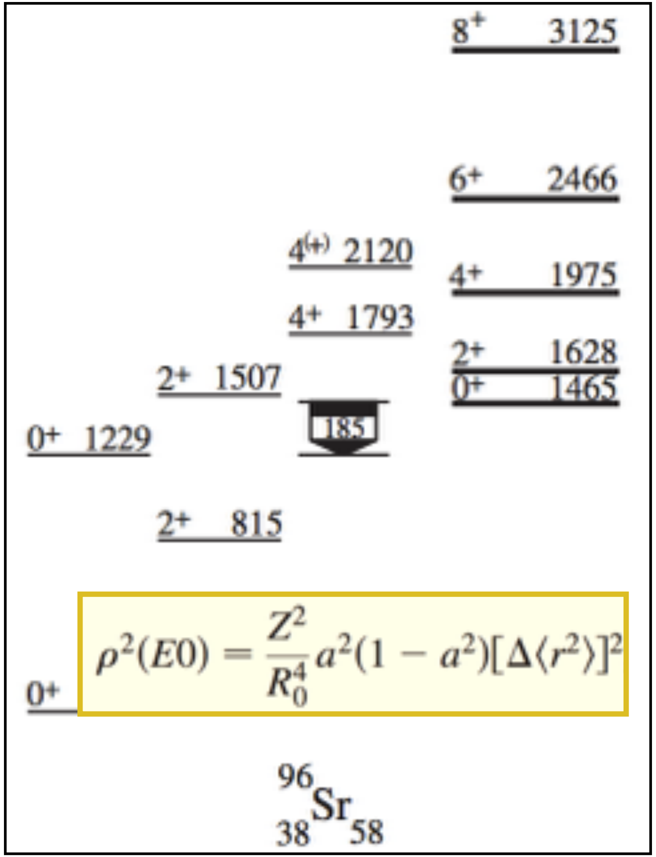

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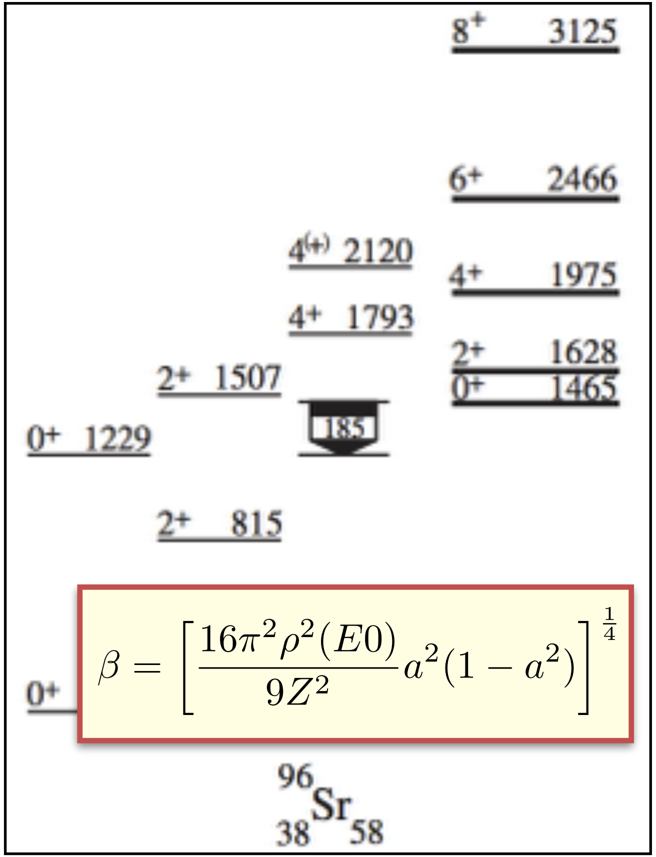

$$\beta = \left[\frac{16\pi^2\rho^2(E0)}{9Z^2}a^2(1-a^2)\right]^{\frac{1}{4}}$$

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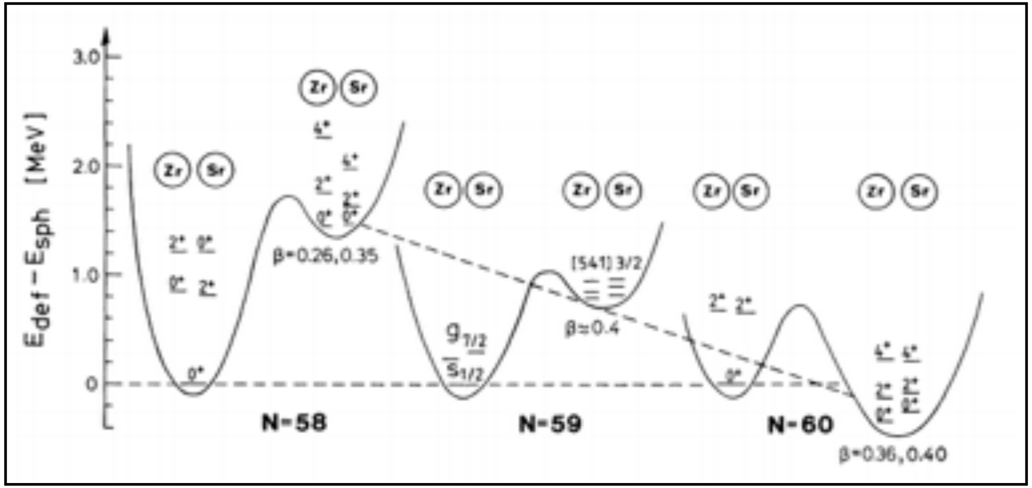
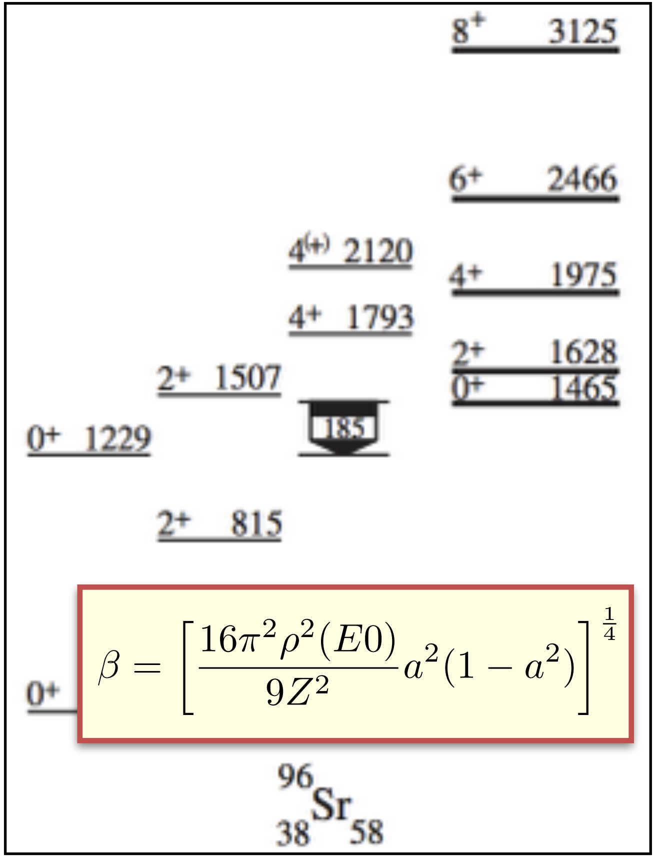
- The strong 0_3^+ (1465 keV) →0_2^+ (1229 keV) E0 transition is characteristic of coexisting shapes.

- The deformed 0_3^+ state at 1465 keV is expected to be the same structure as the ^{98}Sr ground state.



G. Lhersonneau et al., Phys. Rev. C 49, (1994) 1379



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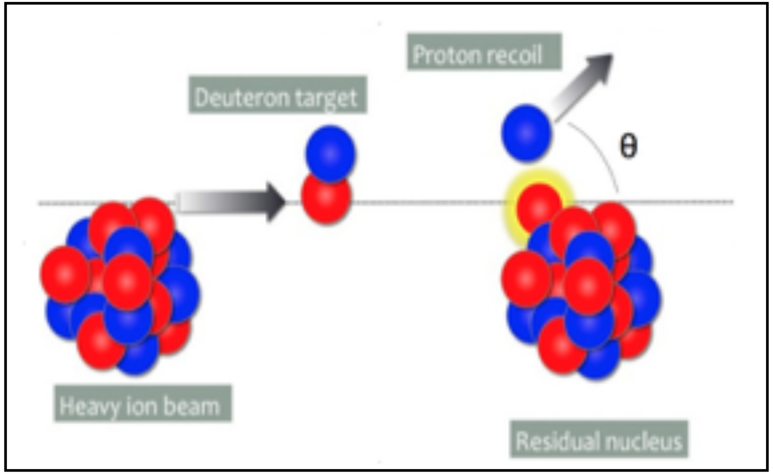
Experimental Campaign

$^{94,95,96}Sr(d,p)$ reactions to study evolution of structure in Sr through low energy single particle states.



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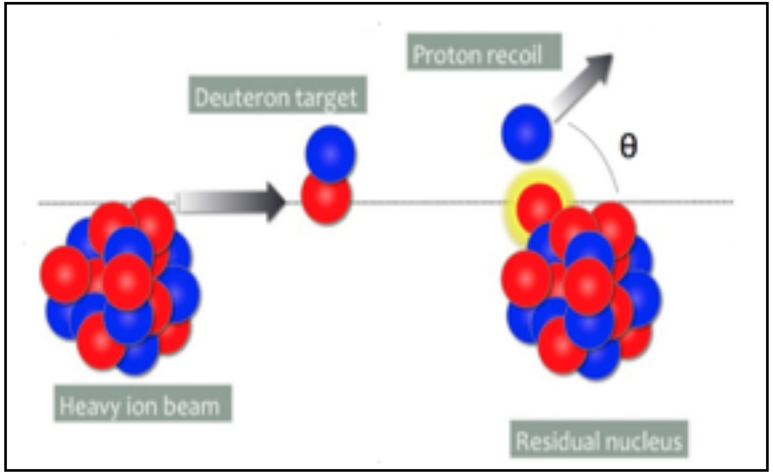
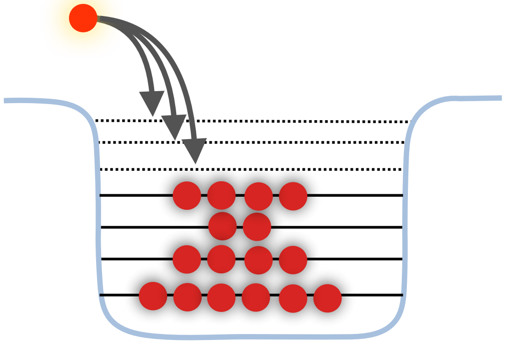


Neutron populates one of the empty single particle orbitals



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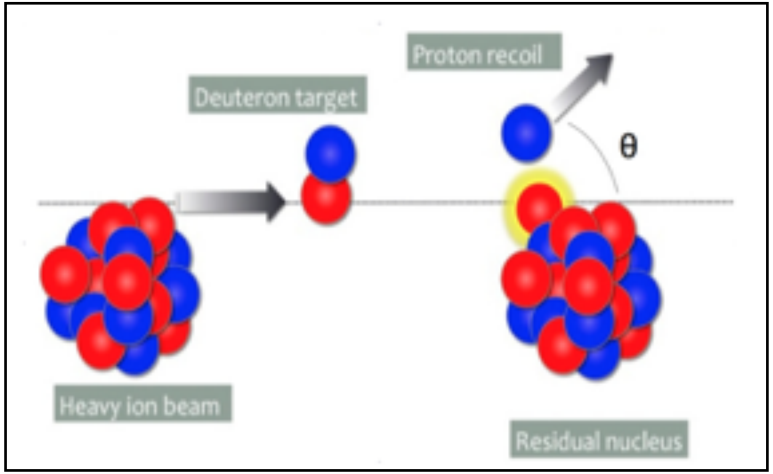

Aims

- Measure angular momentum of Sr states.
- Measure cross section, which gives orbital occupation number.
- Compare occupation numbers to large scale shell model calculations that will be carried out in collaboration with shell model experts.

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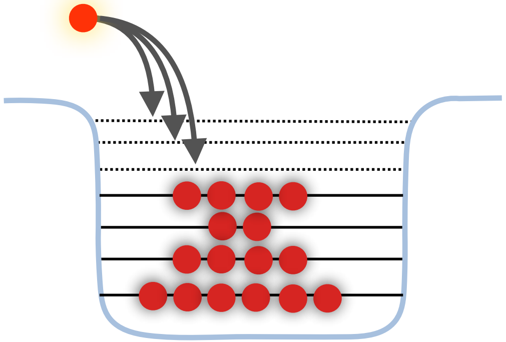
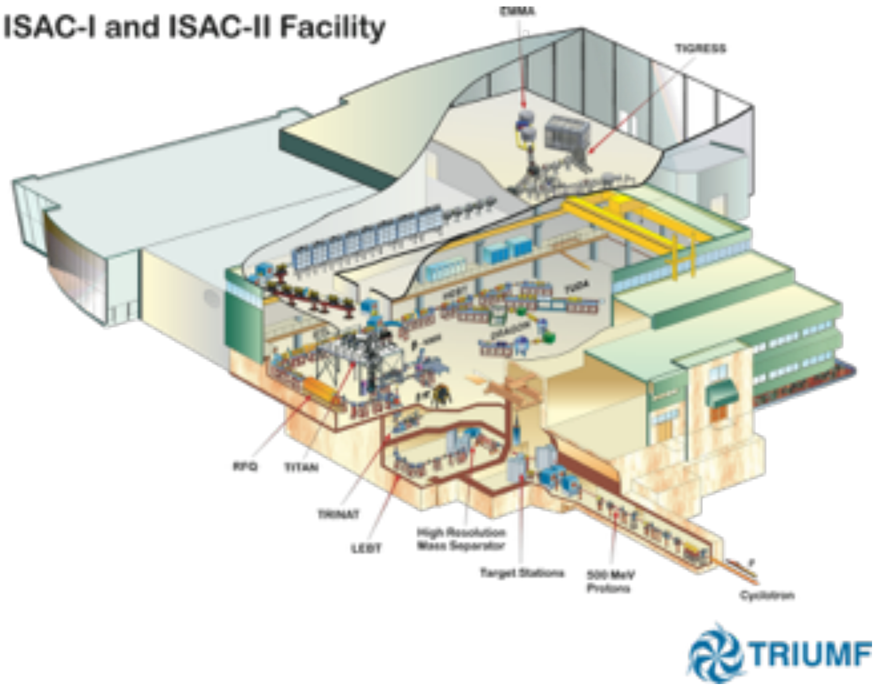


^{95}Sr Beam Delivery at TRIUMF

- A 500 MeV proton beam was impinged on a UCx target.
- Extracted isotopes were laser ionized, mass separated and transported to the CSB where the isotopes were charge bred to 16^{+}.
- Beam re-accelerated to 5.5 MeV/u and impinged on 0.5mg/cm^2 CD_2 target (~10^6 p.p.s) .



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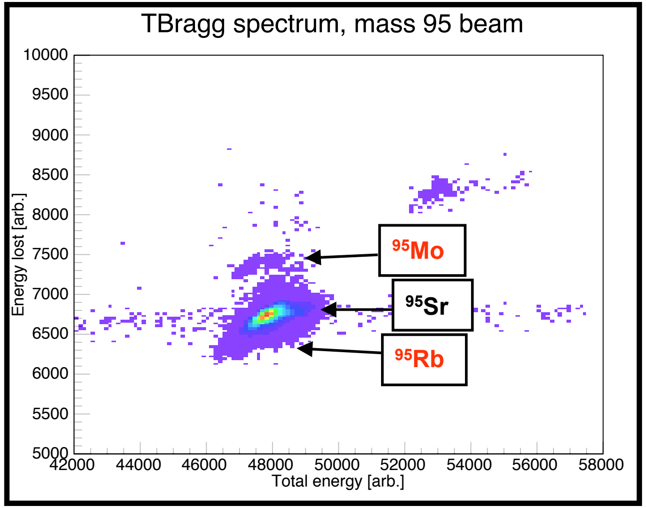
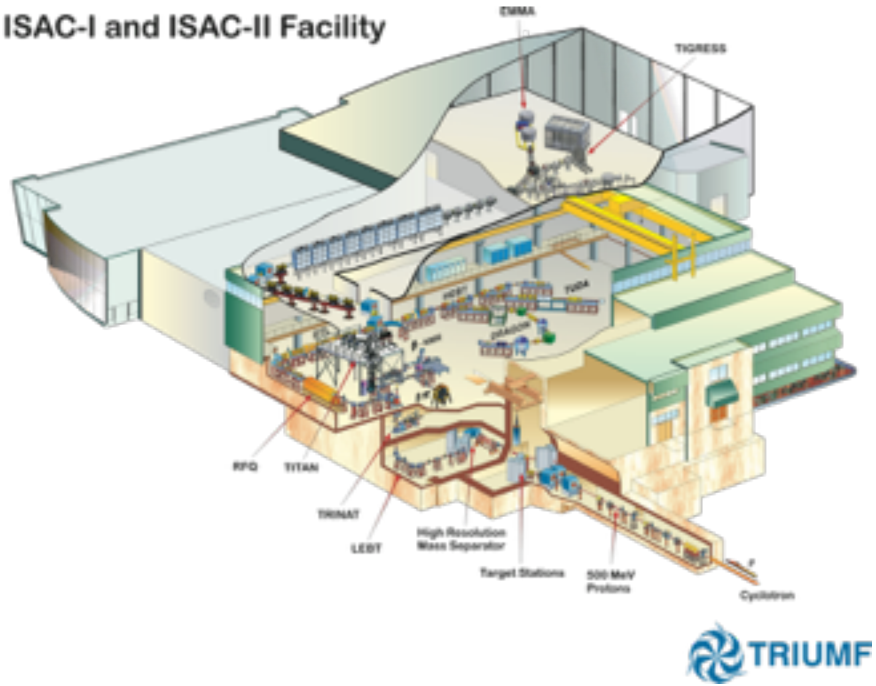


Composition of radioactive beam was ~98% ^{95}Sr.



Sr experiments were first high mass (A>30) experiment using secondary-accelerated beams at TRIUMF.

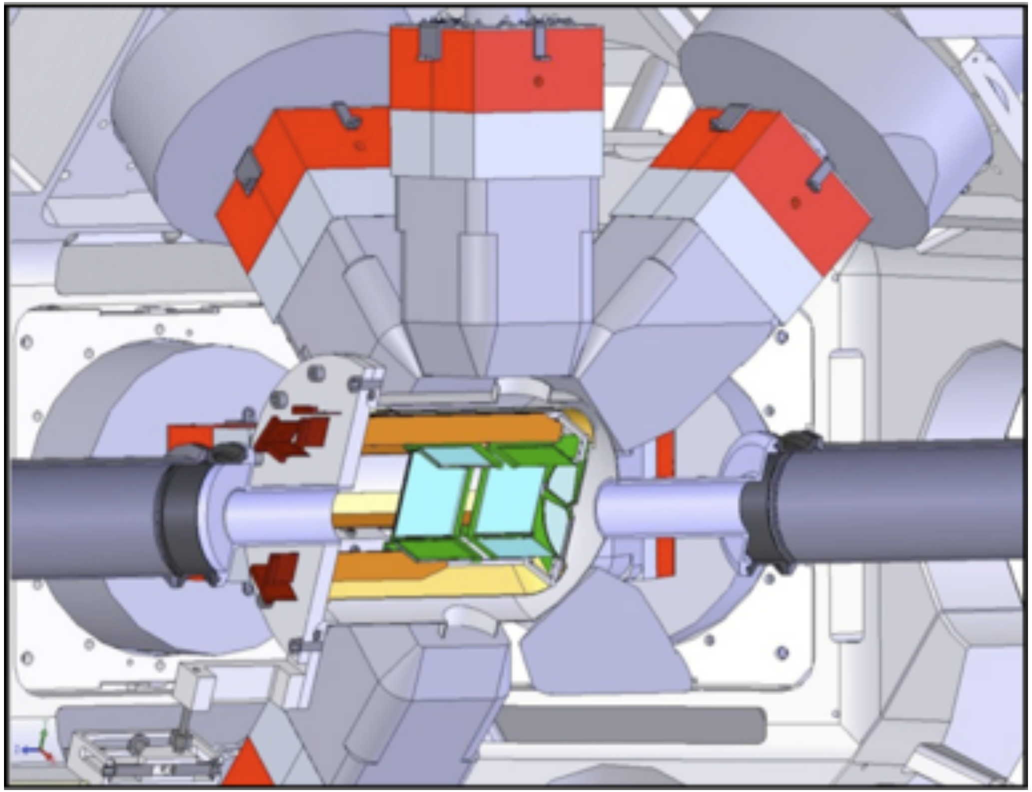
Detector Systems

SHARC

- Silicon detector array.
- Efficiency ≈ 80%.
- Coverage ≈ 80% of 4π.
- Ang. res. ≈ 1°.

TIGRESS

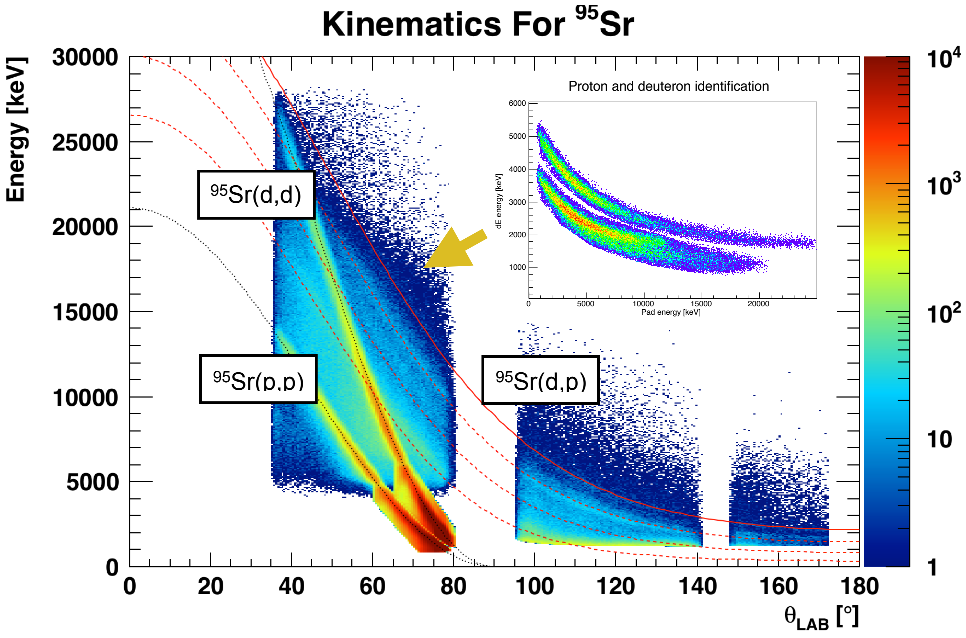
- 12 HPGe Clovers.
- Efficiency (1 MeV) ≈ 10%.
- Coverage ≈ 2π.
- Energy res. (1 MeV) ≈ 2 keV.



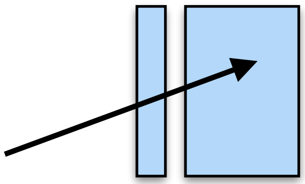
TIGRESS and SHARC detectors were used to enable p-ɣ coincidence measurements.

SHARC Data

- Energy resolution of SHARC makes extracting ^{96}Sr states difficult.
- Large amount of β decay background.



Particle identification used through dE-E detector arrangement



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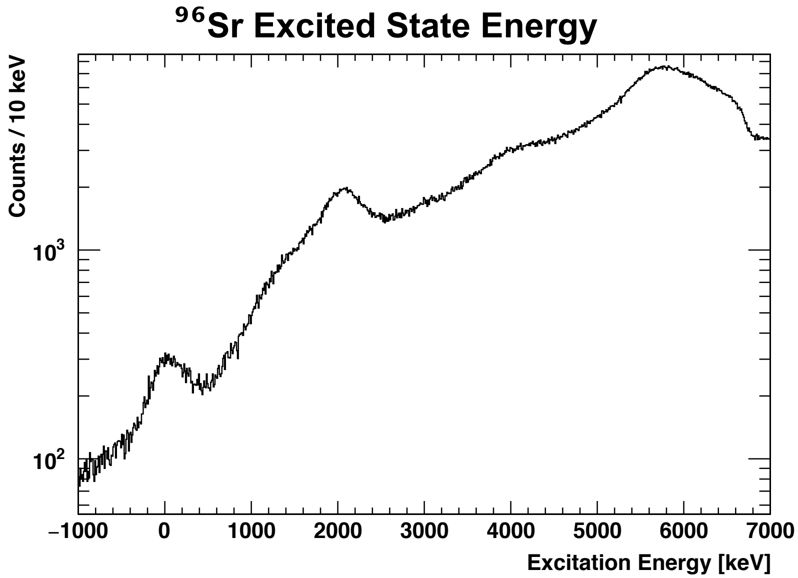

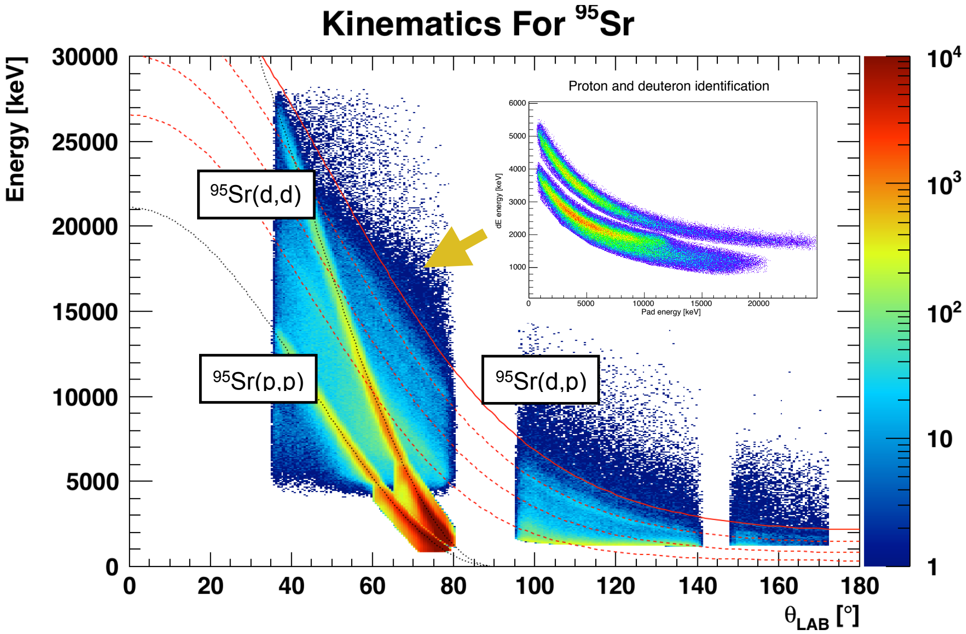

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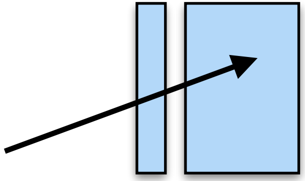
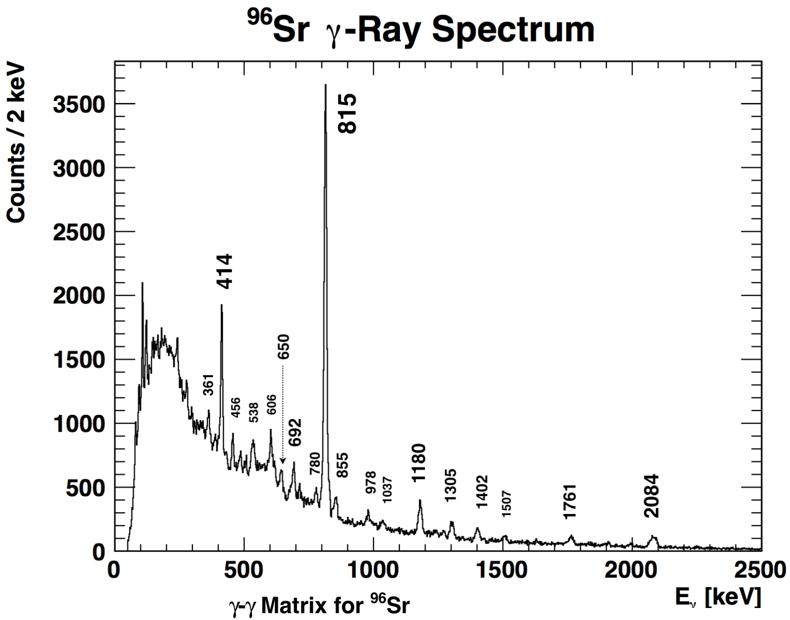
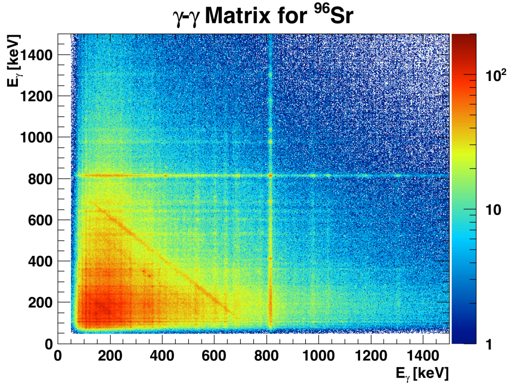


SHARC + TIGRESS Data

- Many ^{96}Sr transitions observed, indicating that many levels are populated.
- We only want directly populated states.





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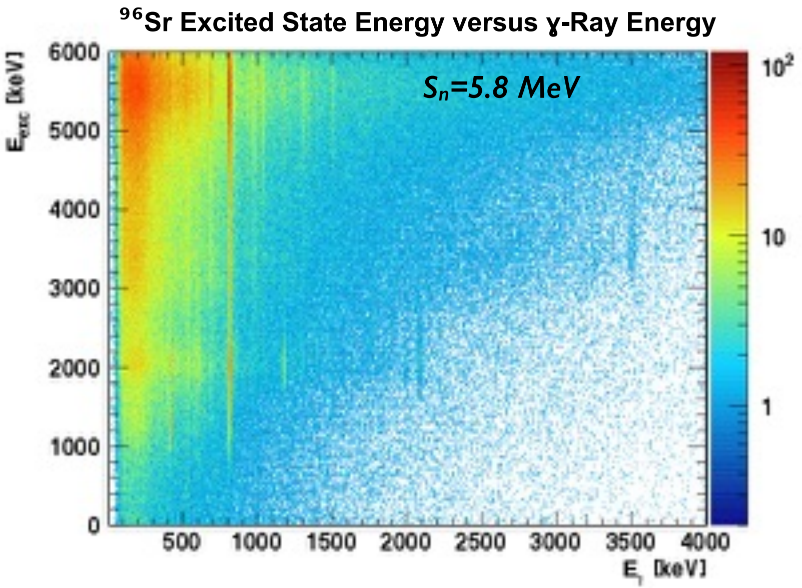

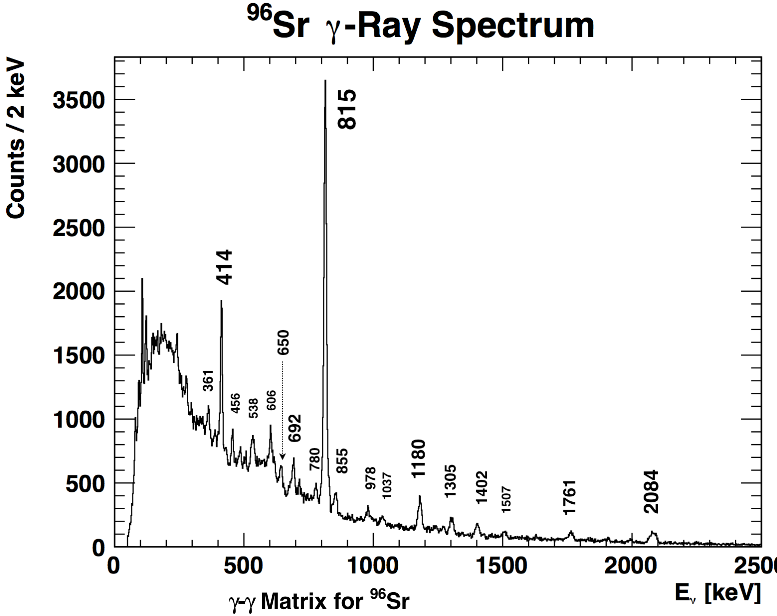

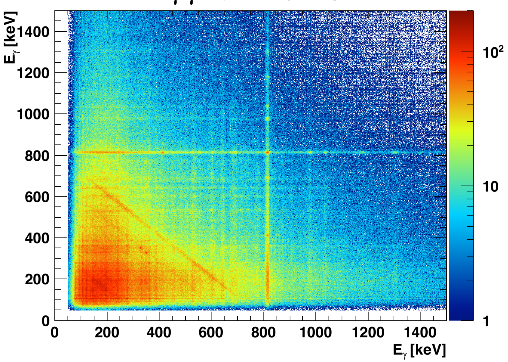

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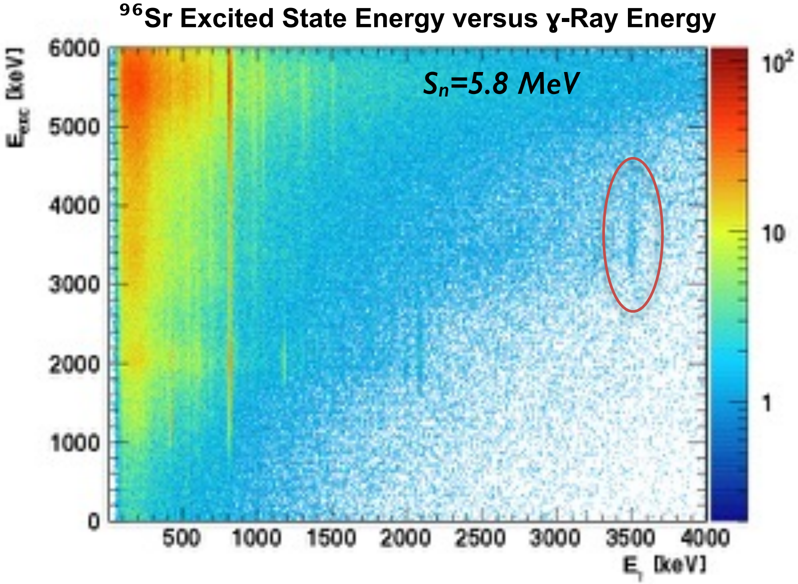
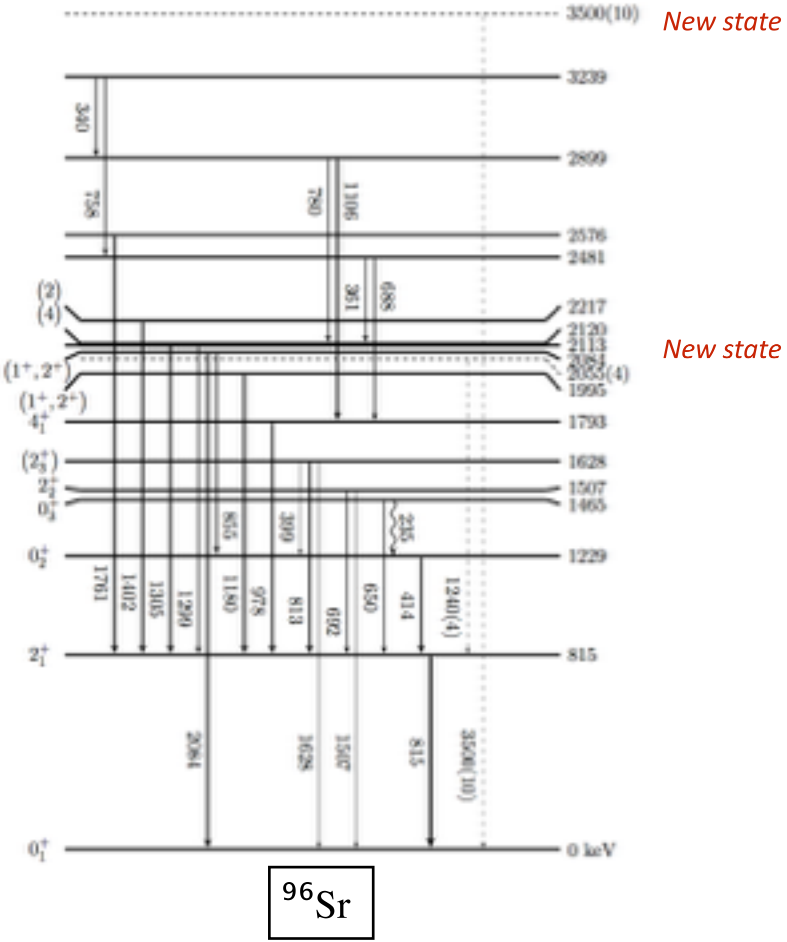
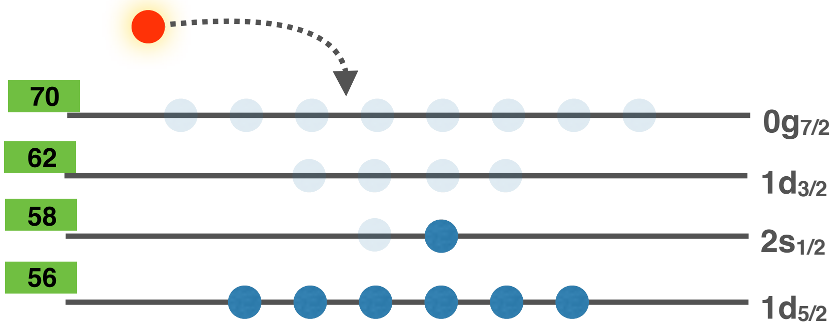




Angular Distribution Analysis

- Transferred neutron populates either 2s½, 1d³⁄₂ or 0g⁷⁄₂ orbital.
- Three different orbital angular momentum transfers; ℓ = 0, 2 or 4.
- Each scenario has a characteristic angular distribution.
- Fit data to DWBA calculations to determine ℓ and $\mathcal{S}$.



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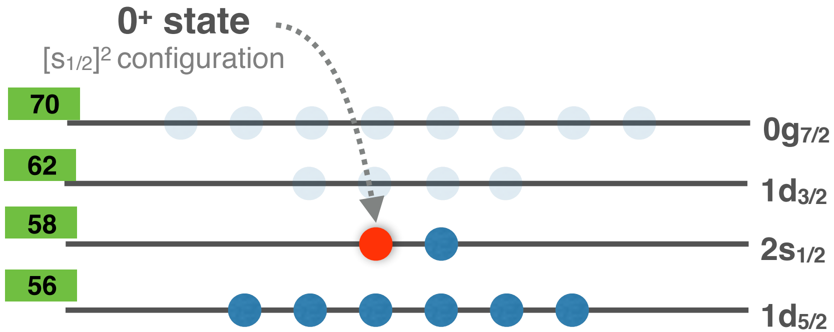

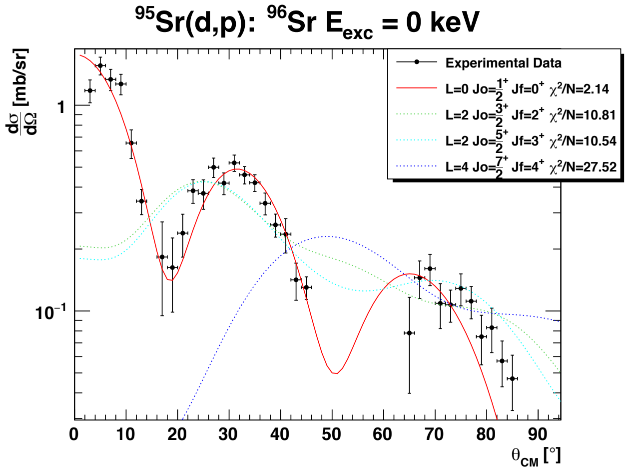

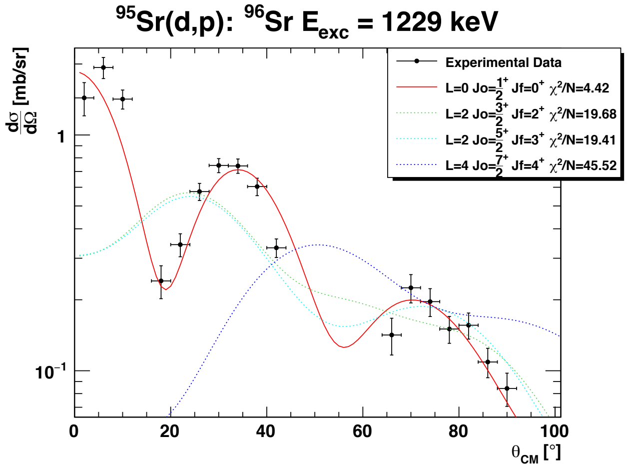

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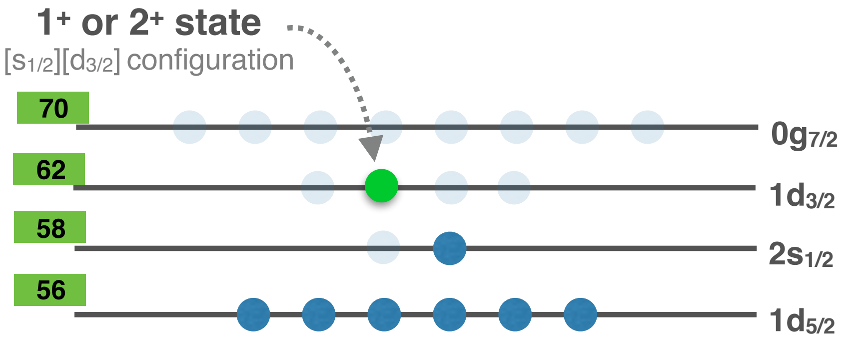

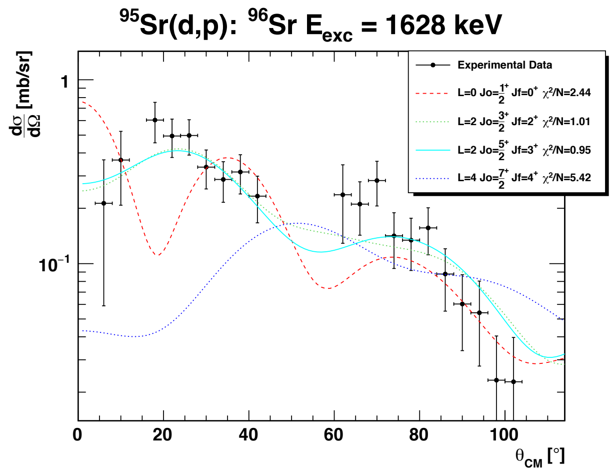

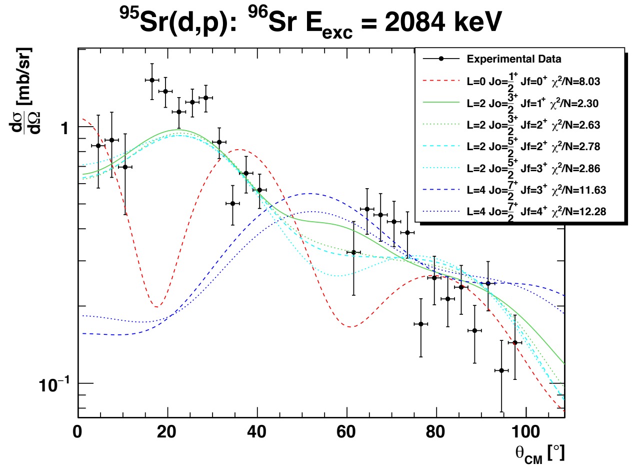

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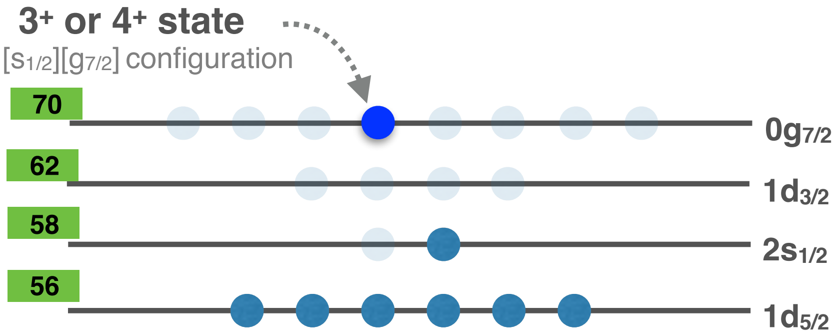
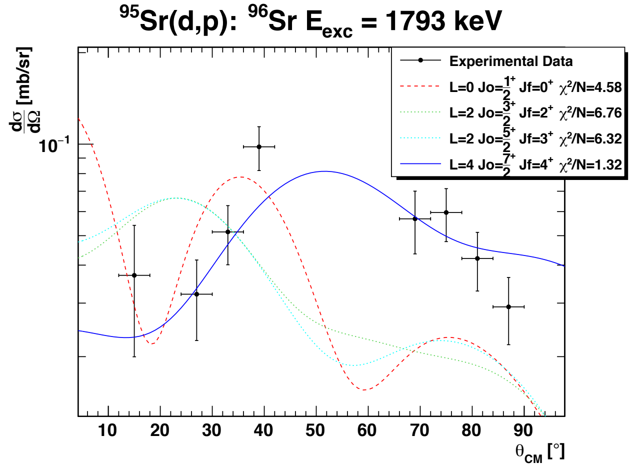
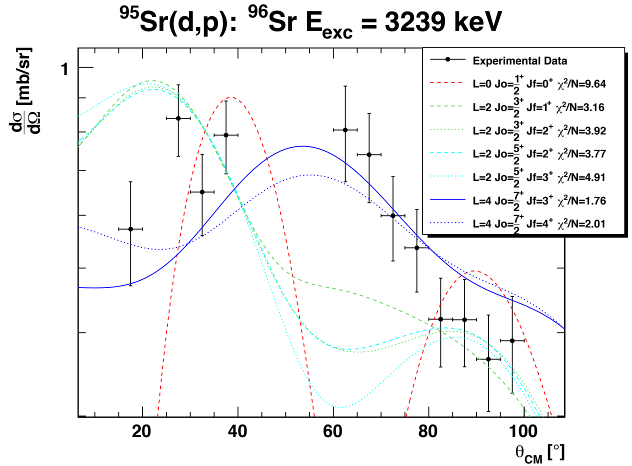
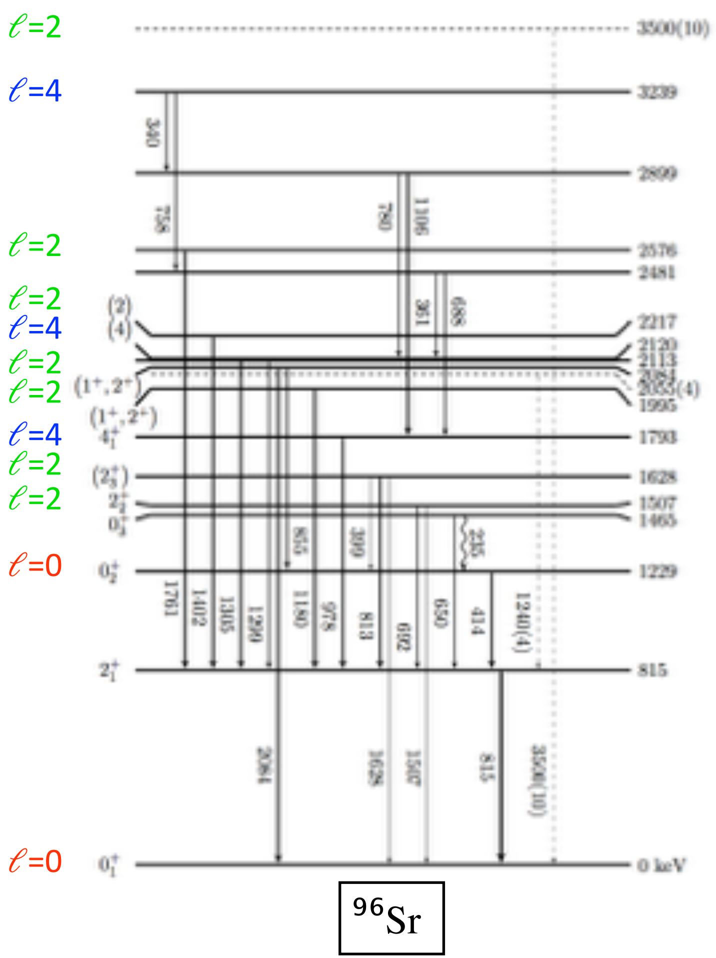






Angular Distribution Results

- Angular distributions were extracted for 12 ^{96}Sr states.
- Shell model calculations are being carried out to compare spectroscopic factors.
- Insufficient statistics to measure angular distribution of 1465 keV ^{96}Sr state.



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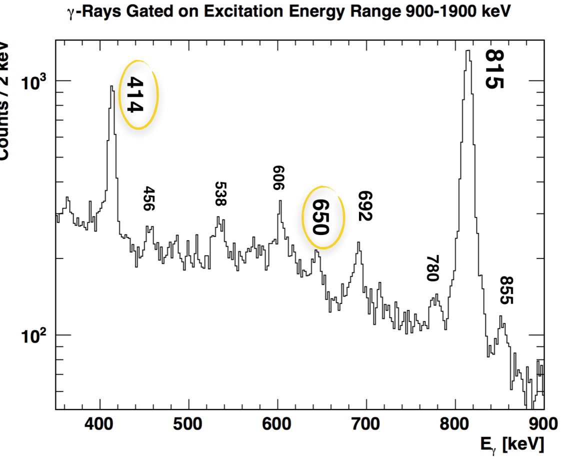
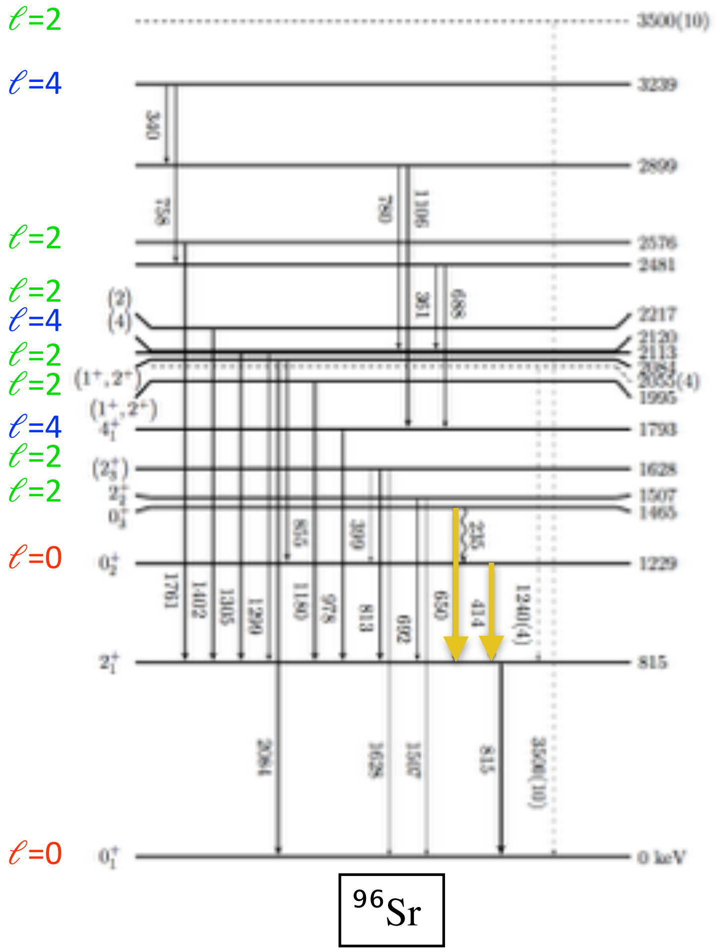
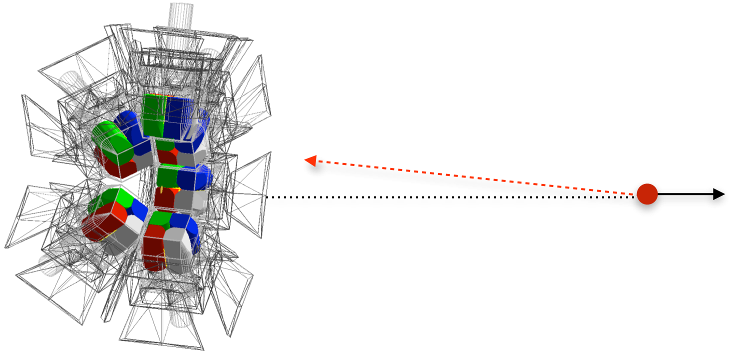
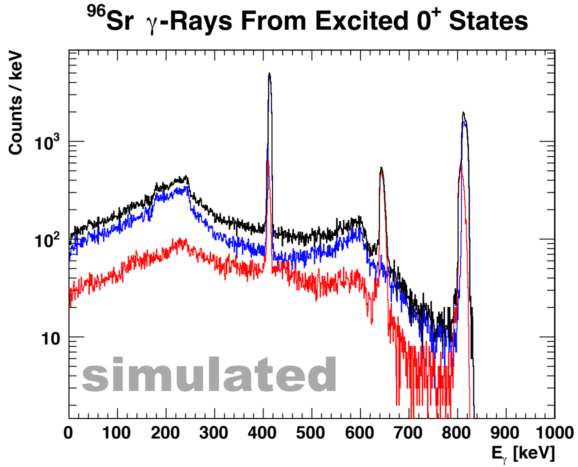




Mixing Between Excited 0^+ States in ^{96}Sr

- Simulate decay of 1229 keV & 1465 keV states using realistic *Geant* model and compare counts.





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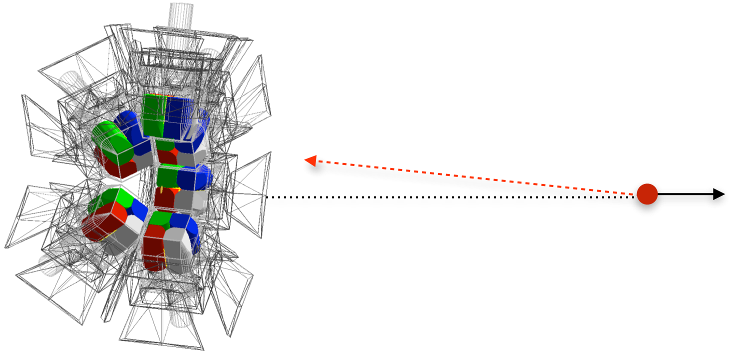
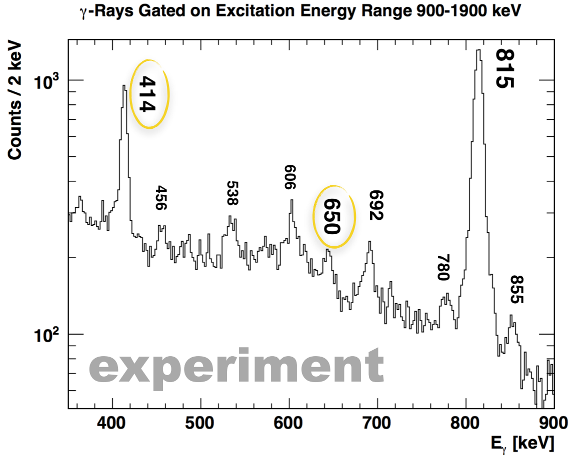
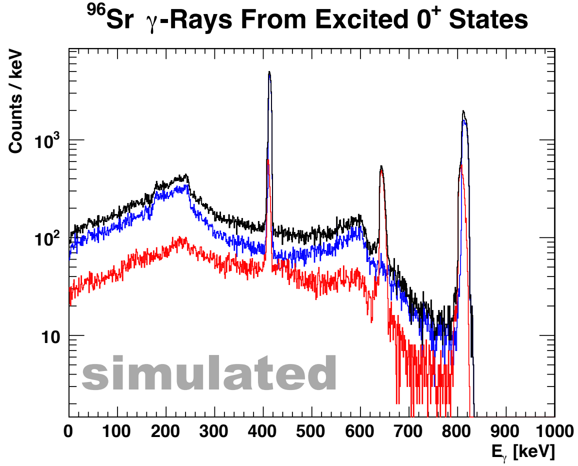
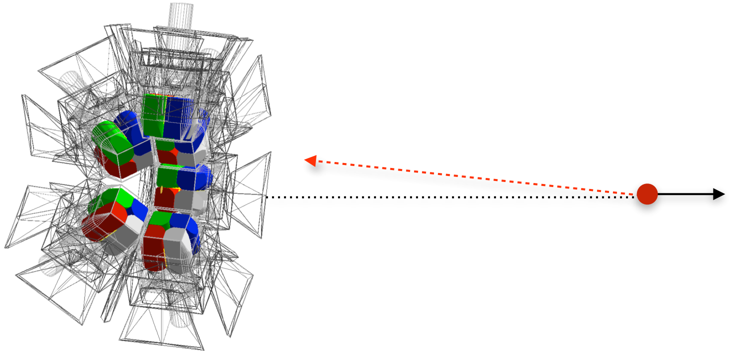


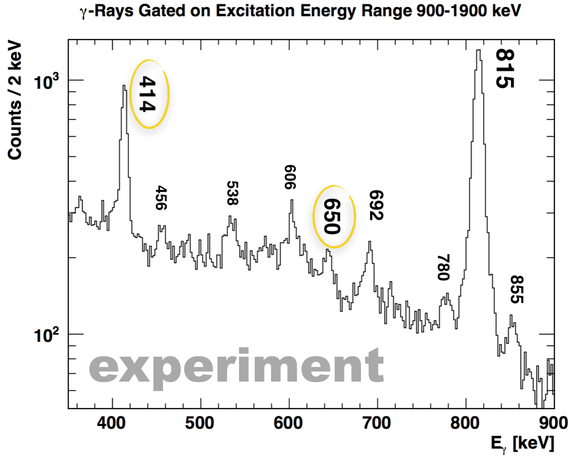


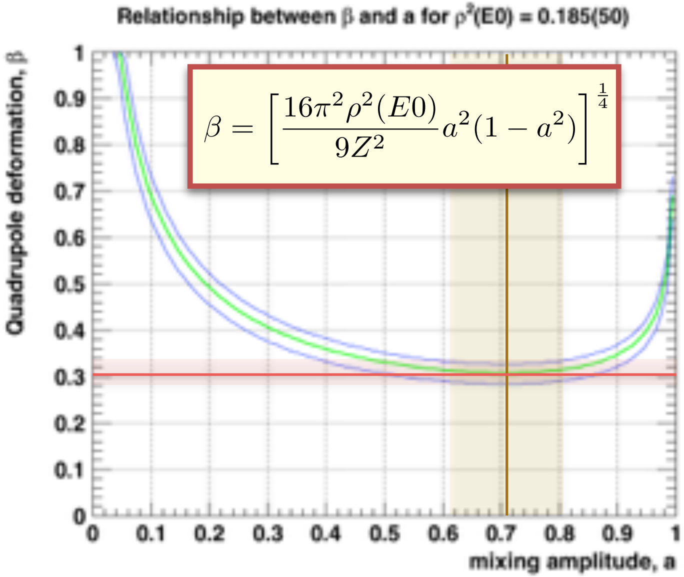


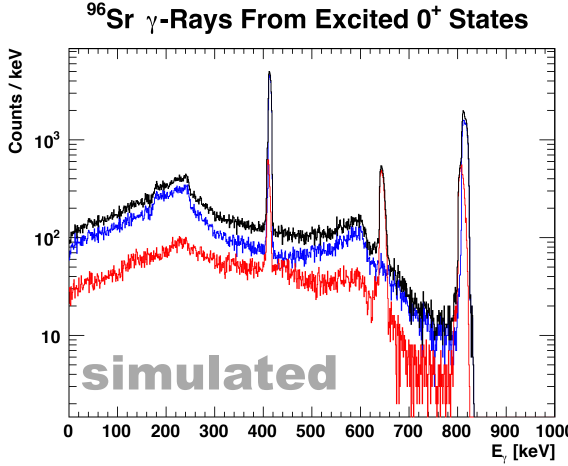
Mixing Between Excited 0^+ States in ^{96}Sr

- Simulate decay of 1229 keV & 1465 keV states using realistic *Geant* model and compare counts.
- Mixing amplitude of 0_3^+: 0_2^+ states, $a^2 = 0.5(2)$.
- Constrains deformation: β = 0.30(5).









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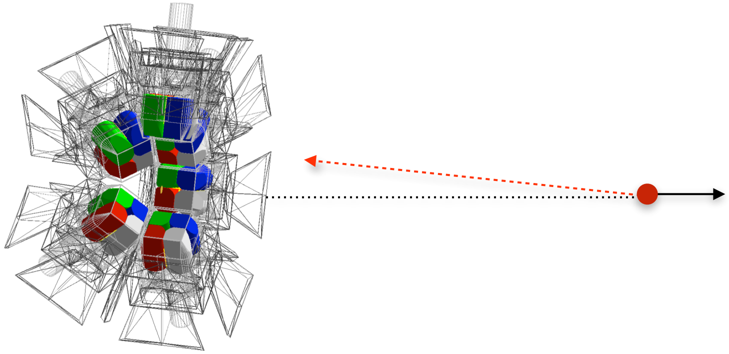
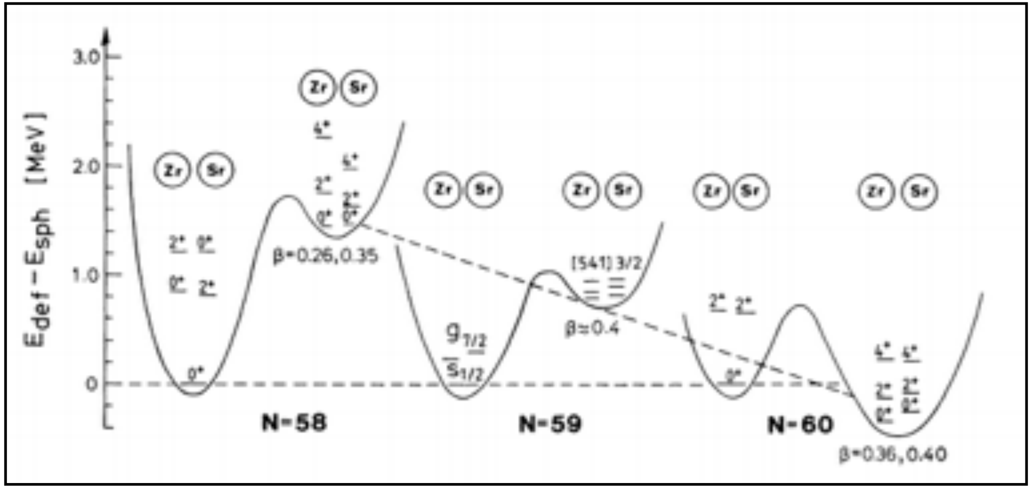




G. Lhersonneau et al., Phys. Rev. C 49, (1994) 1379

Summary

- ^{95}Sr(d,p) to investigate single particle structure of ^{96}Sr states.
- First high mass (A>30) experiments of this kind at TRIUMF.
- Measured 12 angular distributions, including a new state at ~3.5 MeV.
- Extracted information about the state spins and underlying single particle configurations.
- Use γ-ray analysis to measure mixing between excited 0^+ states in ^{96}Sr.

Many thanks to S1389 Collaboration;

P. C. Bender[2], R. Krücken[1,2], K. Wimmer[3], F. Ames[2], C. Andreoiu[4], C. S. Bancroft[3], R. Braid[5], T. Bruhn[2], W. Catford[6], A. Cheeseman[2], D. S. Cross[4], C. Aa. Diget[7], T. Drake[8], A. Garnsworthy[2], G. Hackman[2], R. Kanungo[9], A. Knapton[6], W. Korten[2], K. Kuhn[5], J. Lassen[2], R. Laxdal[2], M. Marchetto[2], A. Matta[6], D. Miller[2], M. Moukaddam[2], N. Orr[10], N. Sachmpazidi[3], A. Sanetullaev[2], N. Termpstra[3], C. Unsworth[2], P. J. Voss[4]

1. University of British Columbia, 2. TRIUMF, 3. Central Michigan University, 4. Simon Fraser University, 5. Colorado School of Mines, 6. University of Surrey, 7. University of York, 8. University of Toronto, 9. Saint Mary's University, 10. LPC Caen.

CINP Canadian Institute of Nuclear Physics ICPN Institut canadien de physique nucléaire

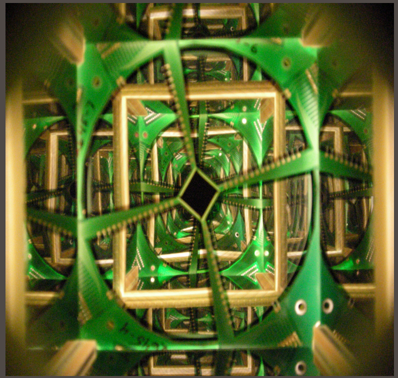
Science & Technology Facilities Council

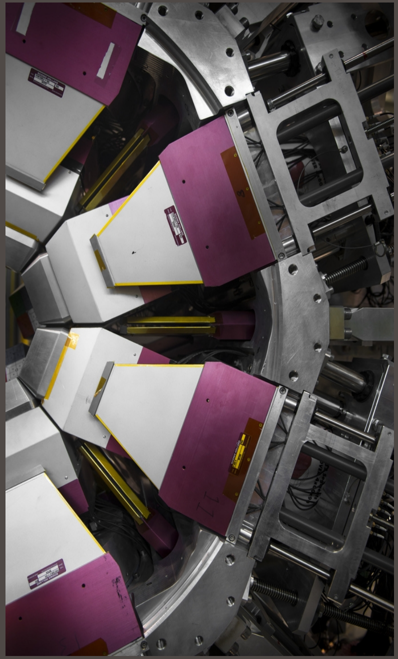
NSERC CRSNG

NRC·CNRC

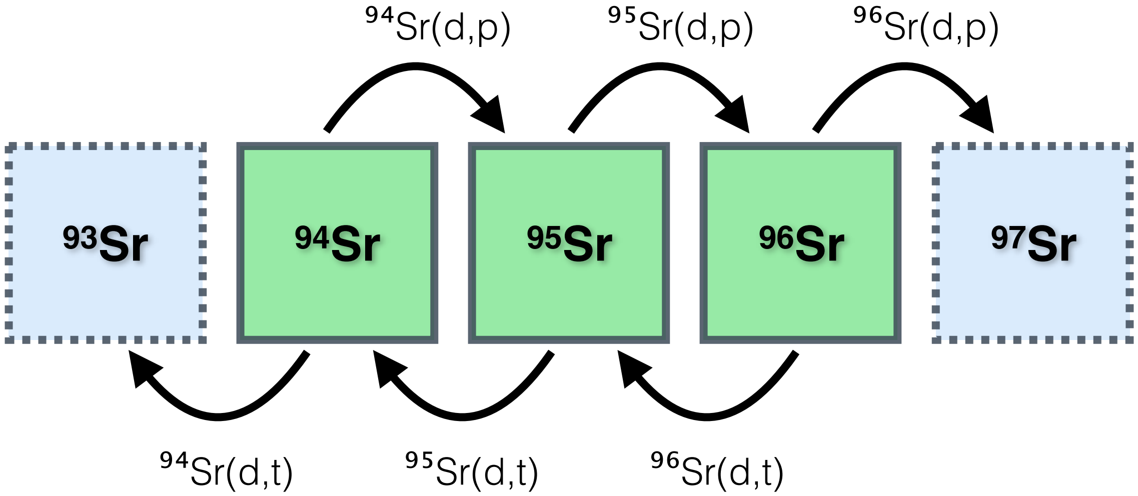
Thank you!
Merci!

Follow us at TRIUMFLab



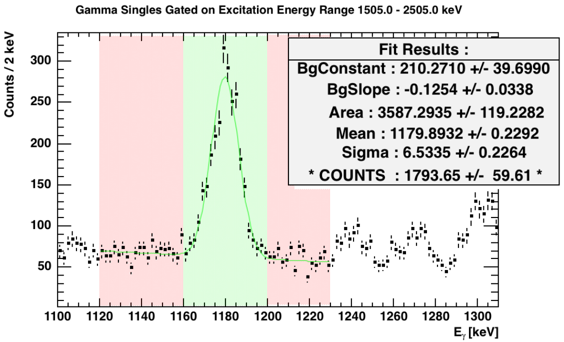


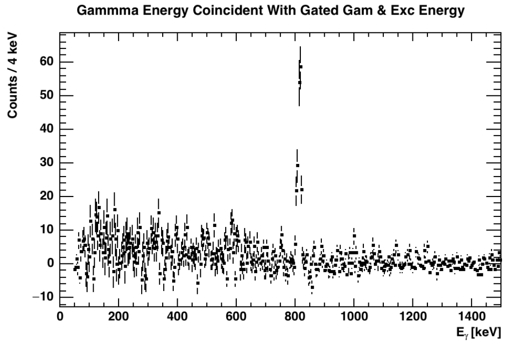
Experimental Campaign

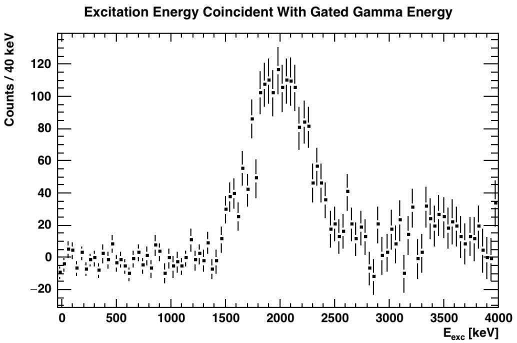


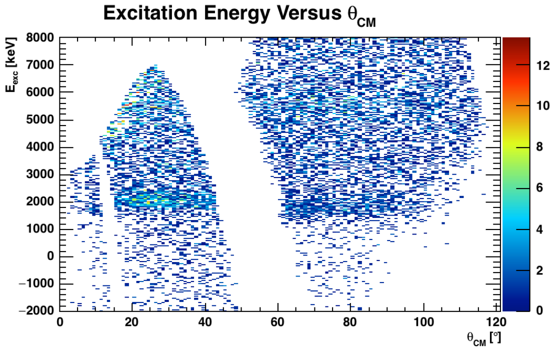
Angular Distribution Analysis

- Upper left: Identified 1180 keV γ-ray transition
- Upper right: Coincident γ-rays.
- Bottom left: Excitation energy coincident with 1180 keV γ-ray.
- Bottom right: Excitation energy versus θ_{cm} coincident with 1180 keV γ-ray.









TRIUMF

Angular Distribution Analysis

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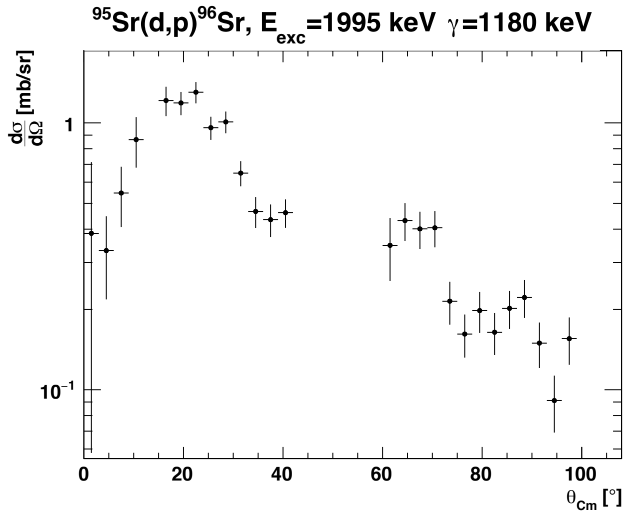
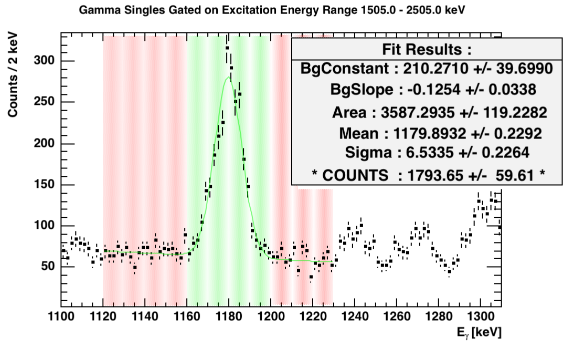
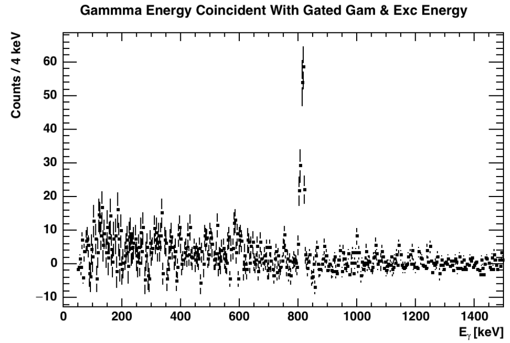
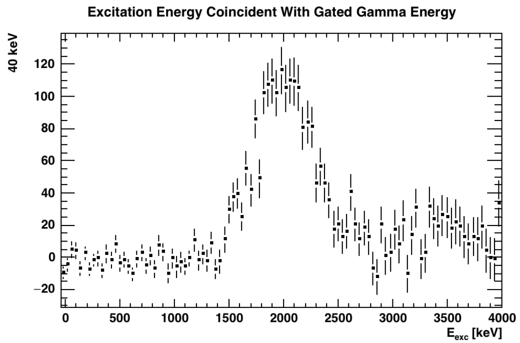
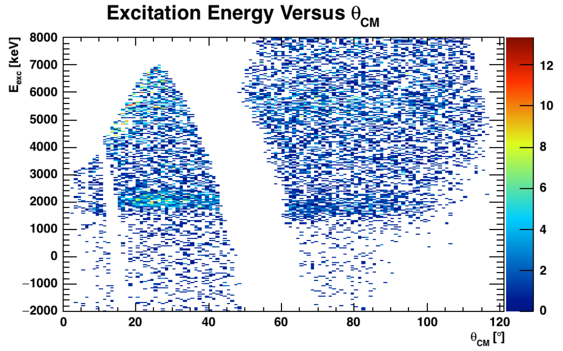




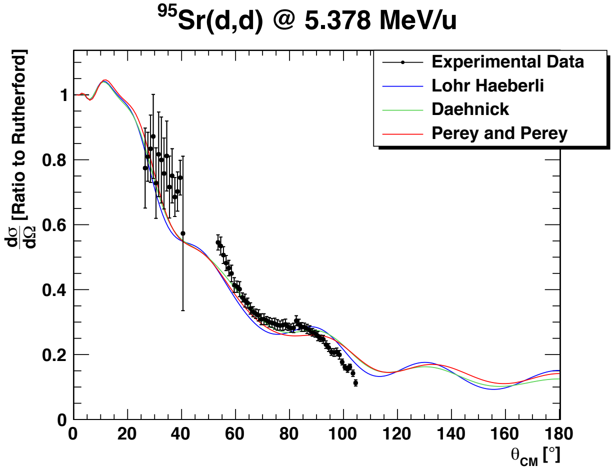




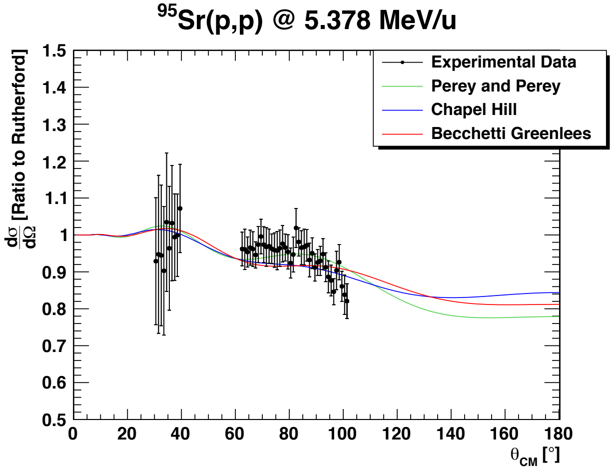


Angular distribution for 1995 keV ^{96}Sr state.

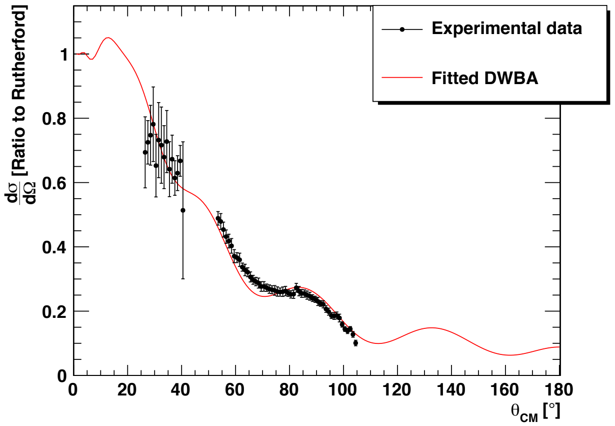
DWBA



^{95}Sr(d,d) @ 5.378 MeV/u
Experimental Data
Lohr Haeberli
Daehnick
Perey and Perey
$\frac{d\sigma}{d\Omega}$ [Ratio to Rutherford]
θ_{CM} [°]

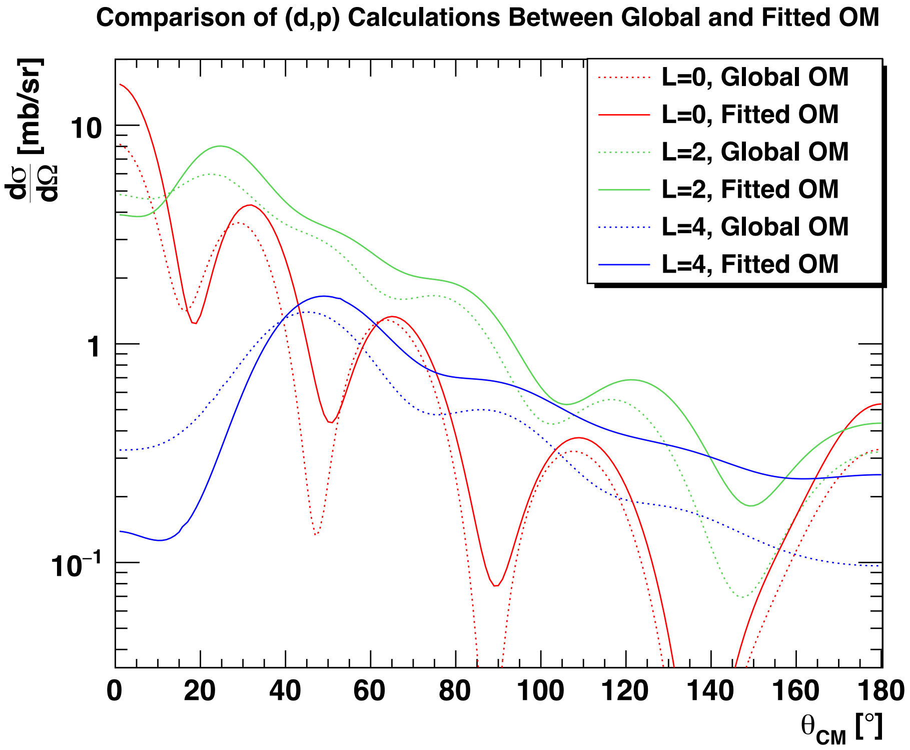


^{95}Sr(p,p) @ 5.378 MeV/u
Experimental Data
Perey and Perey
Chapel Hill
Becchetti Greenlees
$\frac{d\sigma}{d\Omega}$ [Ratio to Rutherford]
θ_{CM} [°]



Experimental data
Fitted DWBA
$\frac{d\sigma}{d\Omega}$ [Ratio to Rutherford]
θ_{CM} [°]

TRIUMF



Comparison of (d,p) Calculations Between Global and Fitted OM
L=0, Global OM
L=0, Fitted OM
L=2, Global OM
L=2, Fitted OM
L=4, Global OM
L=4, Fitted OM
$\frac{d\sigma}{d\Omega}$ [mb/sr]
10
1
10^{-1}
0
20
40
60
80
100
120
140
160
180
θ_{CM} [°]