

Studying the high-momentum neutron in nuclei by $^{16}\text{O}(\text{p},\text{d})$ transfer reactions

— Search for the effect of tensor interactions

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for GSI-s436 collaborations



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- Summary

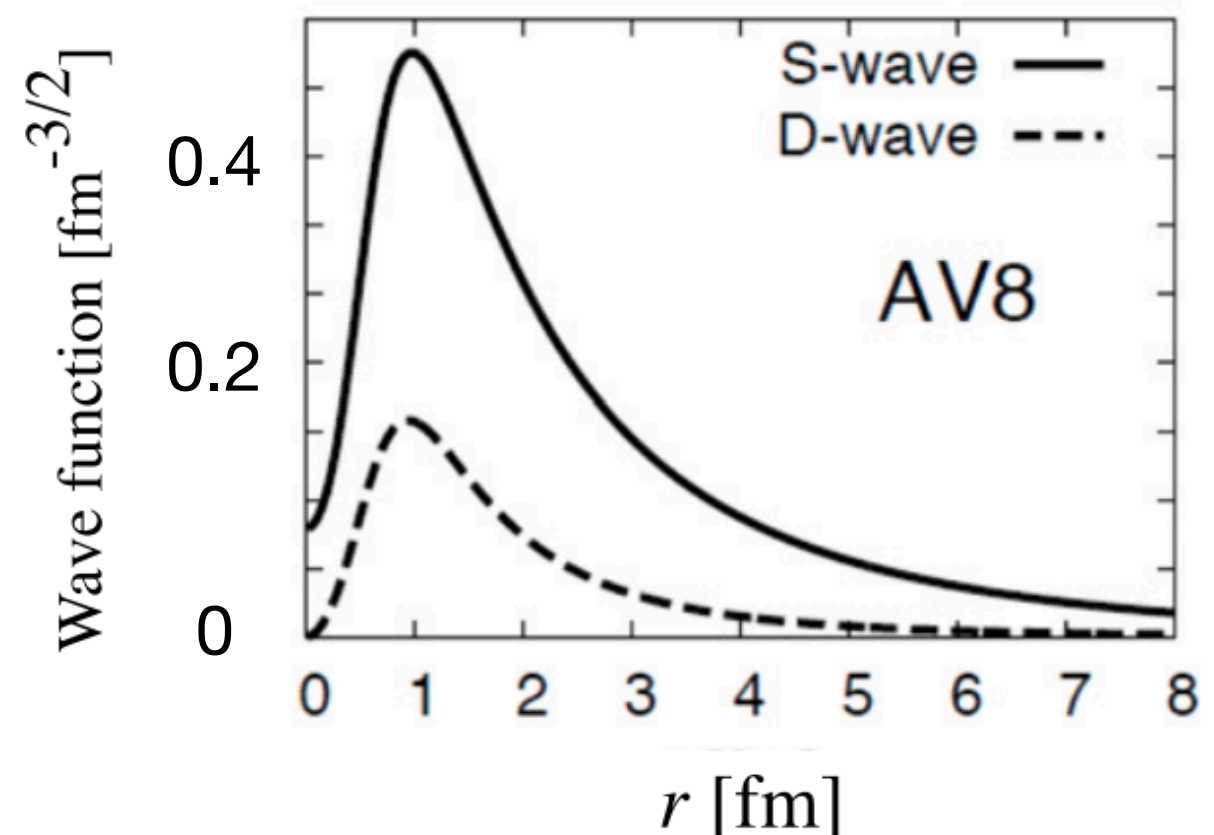
Tensor Interactions

- Pion exchange interaction includes: central, tensor ...

- Tensor operator
- $$S_{12}(\hat{q}) = \sqrt{24\pi/5} \left([\vec{\sigma}_1 \times \vec{\sigma}_2]^{(2)} \cdot Y^{(2)}(\hat{q}) \right)$$
-

Selection Rule: $\Delta J=0, \Delta L=\Delta S=2$

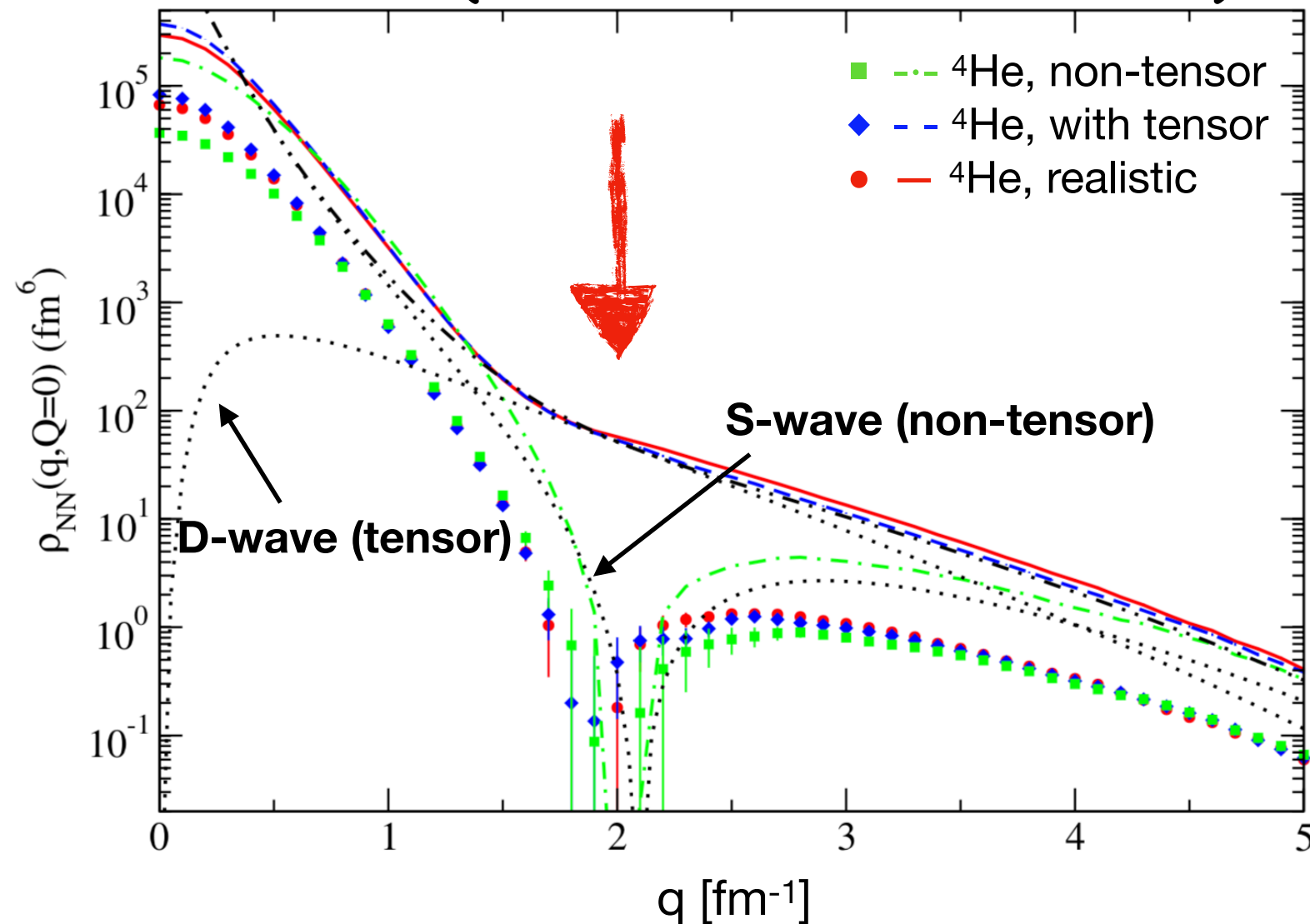
- Binding of deuteron
- Mixing of S- and D-wave in wave functions
- D-wave: peak at smaller r
→ high momentum component



Courtesy of T. Myo

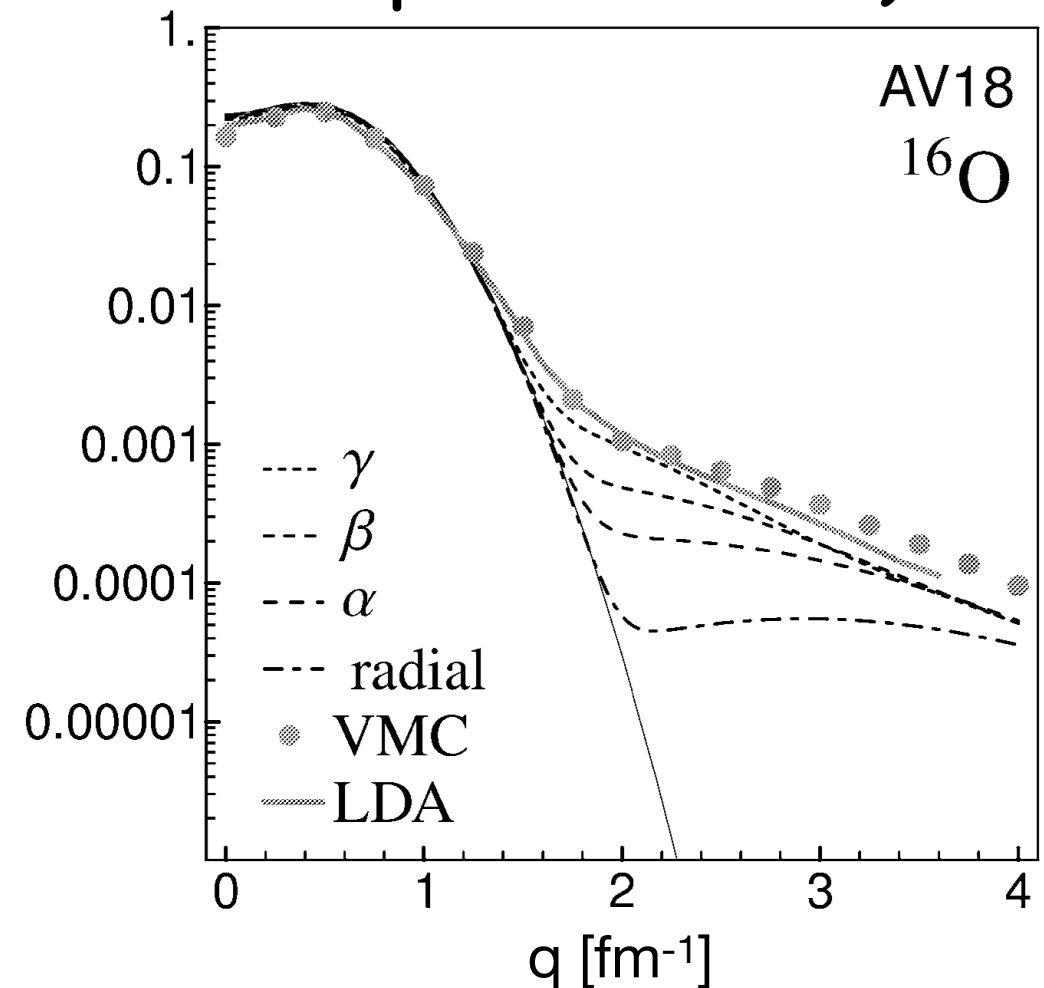
Theoretical prediction for high-momentum component

GFMC (Green-function Monte-Carlo)



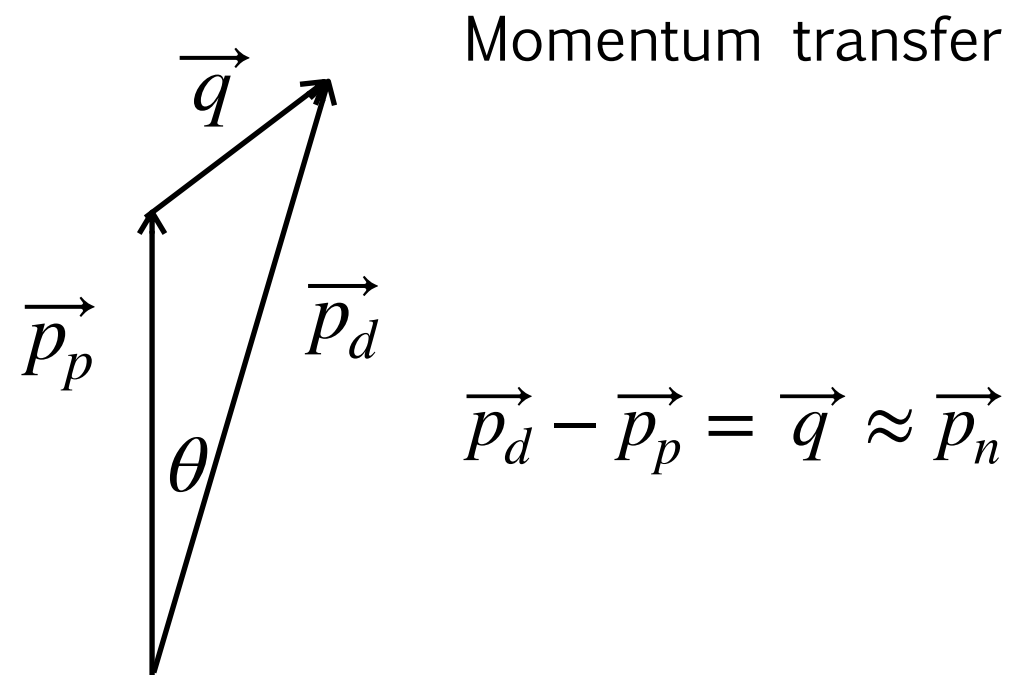
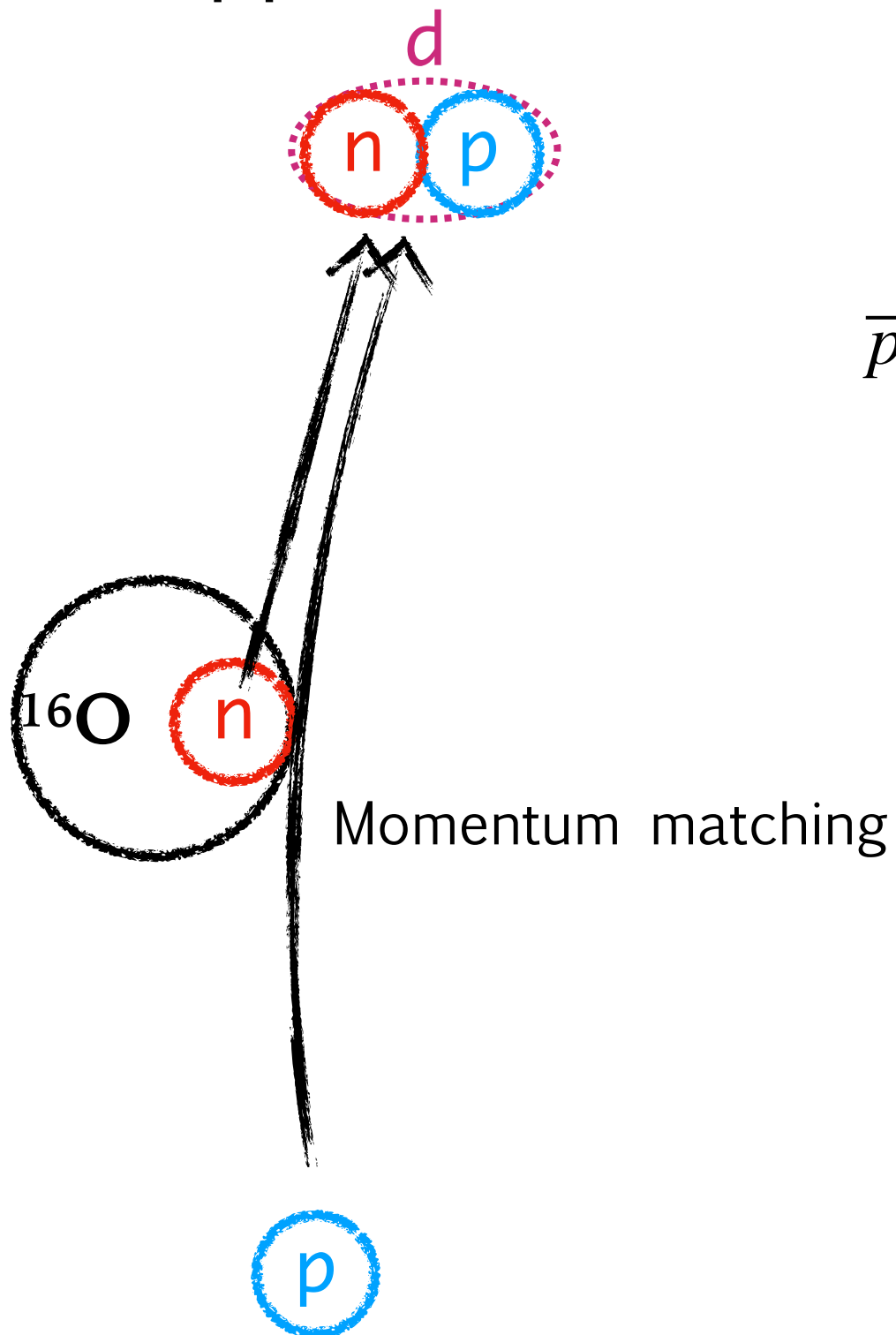
Schiavilla R et al. 2007 Phys. Rev. Lett. 98 132501

UCOM (Unitary Correlation Operator Method)



Neff T et al. 2003 Nucl. Phys. A 713 311

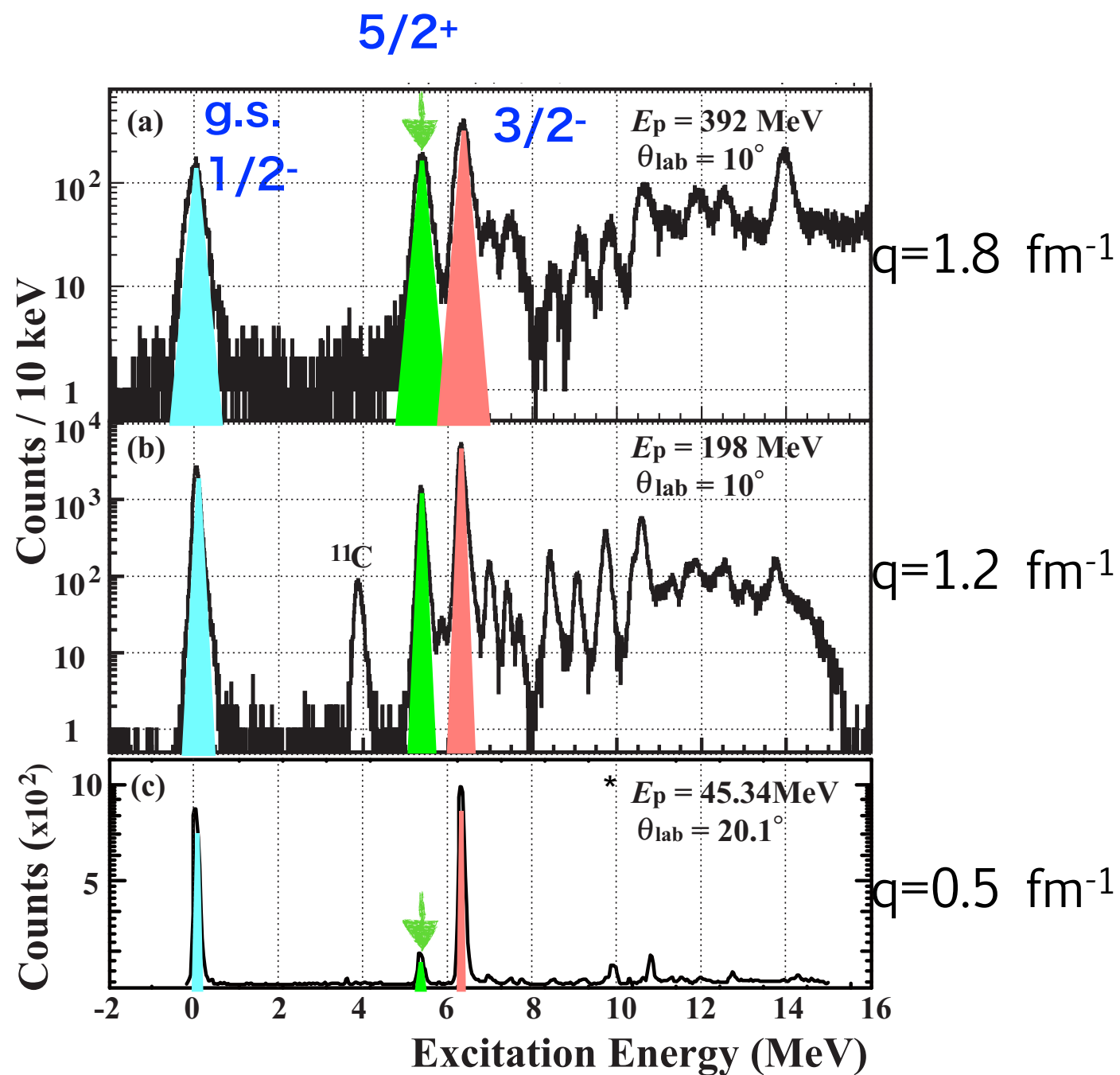
Experimental approach



Momentum transfer

$$\vec{p}_d - \vec{p}_p = \vec{q} \approx \vec{p}_n$$

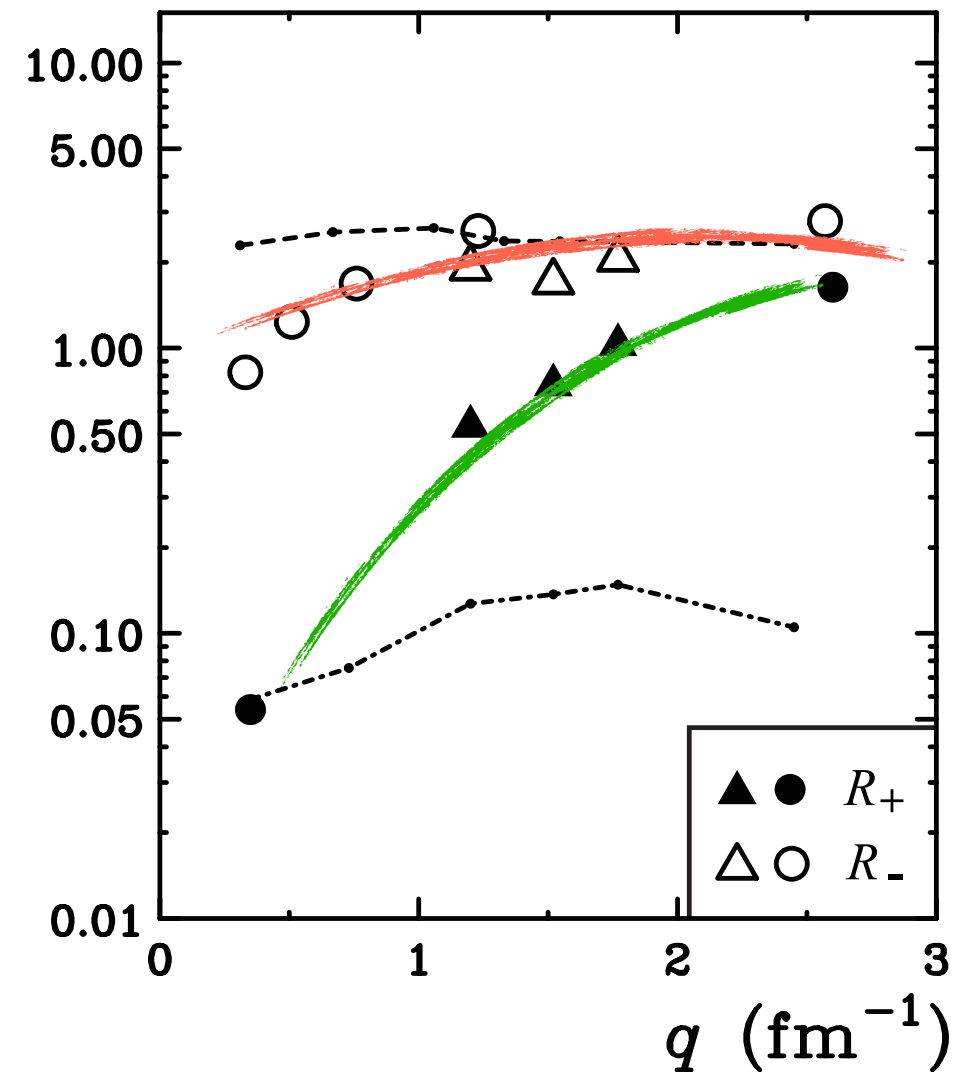
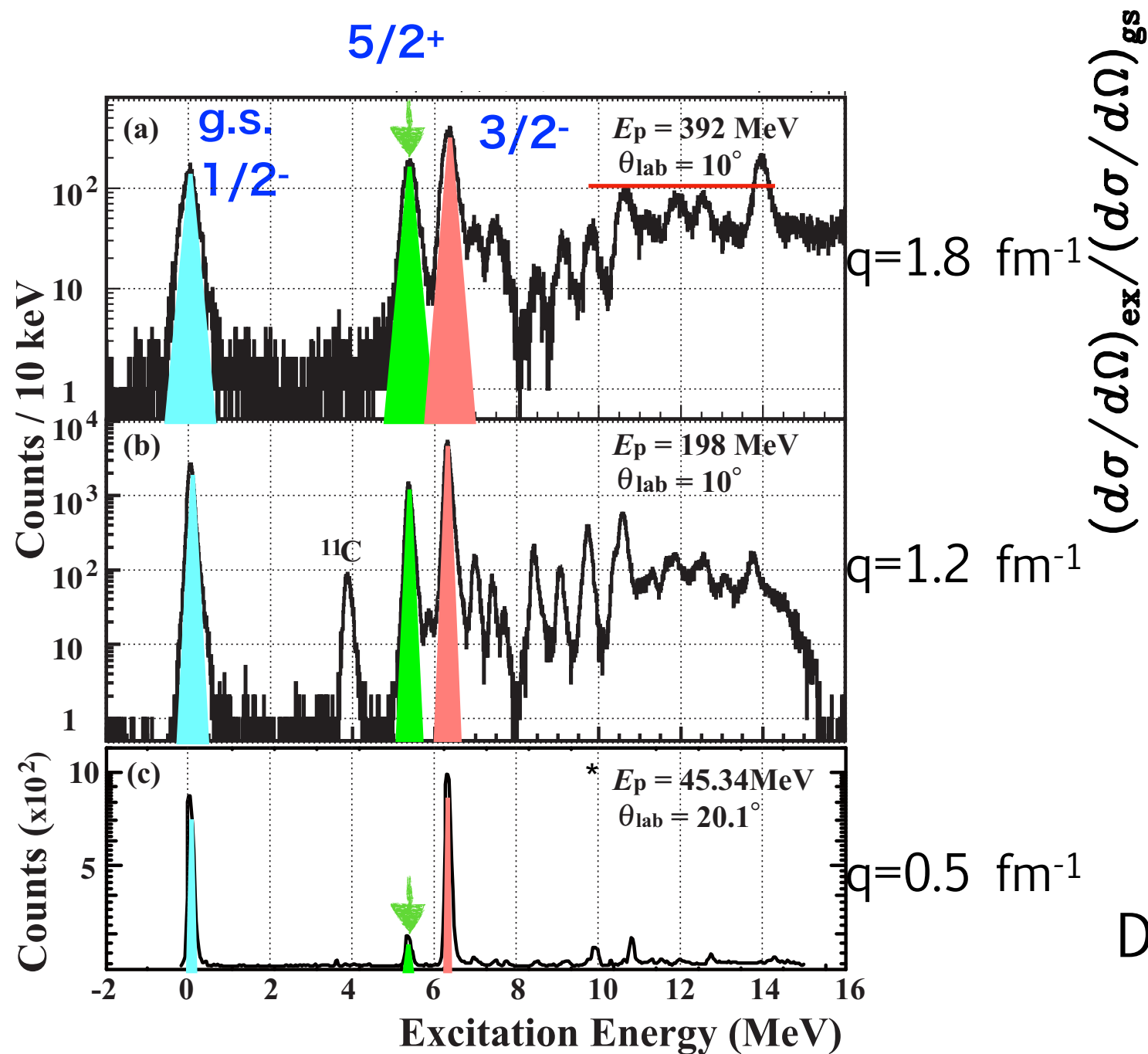
Cross-section $\sigma \propto \rho(p_n)$



$7/2^+$	_____	7.28
$3/2^+$	_____	6.79
$3/2^-$	_____	6.18
$5/2^+$	_____	5.24
$1/2^-$	_____	0
15O		

392, 198 MeV: Ong HJ et al., PLB 725, 277(2013)

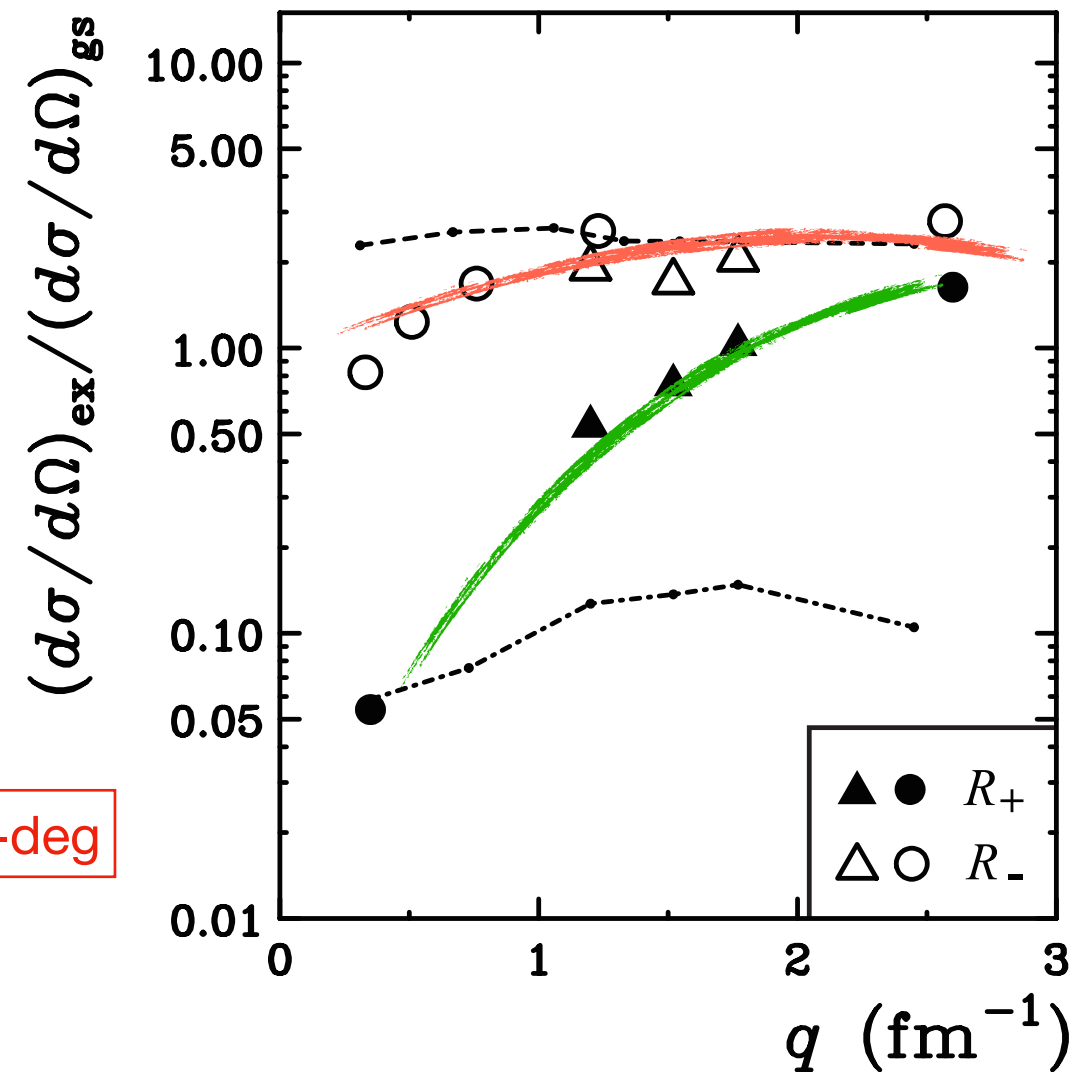
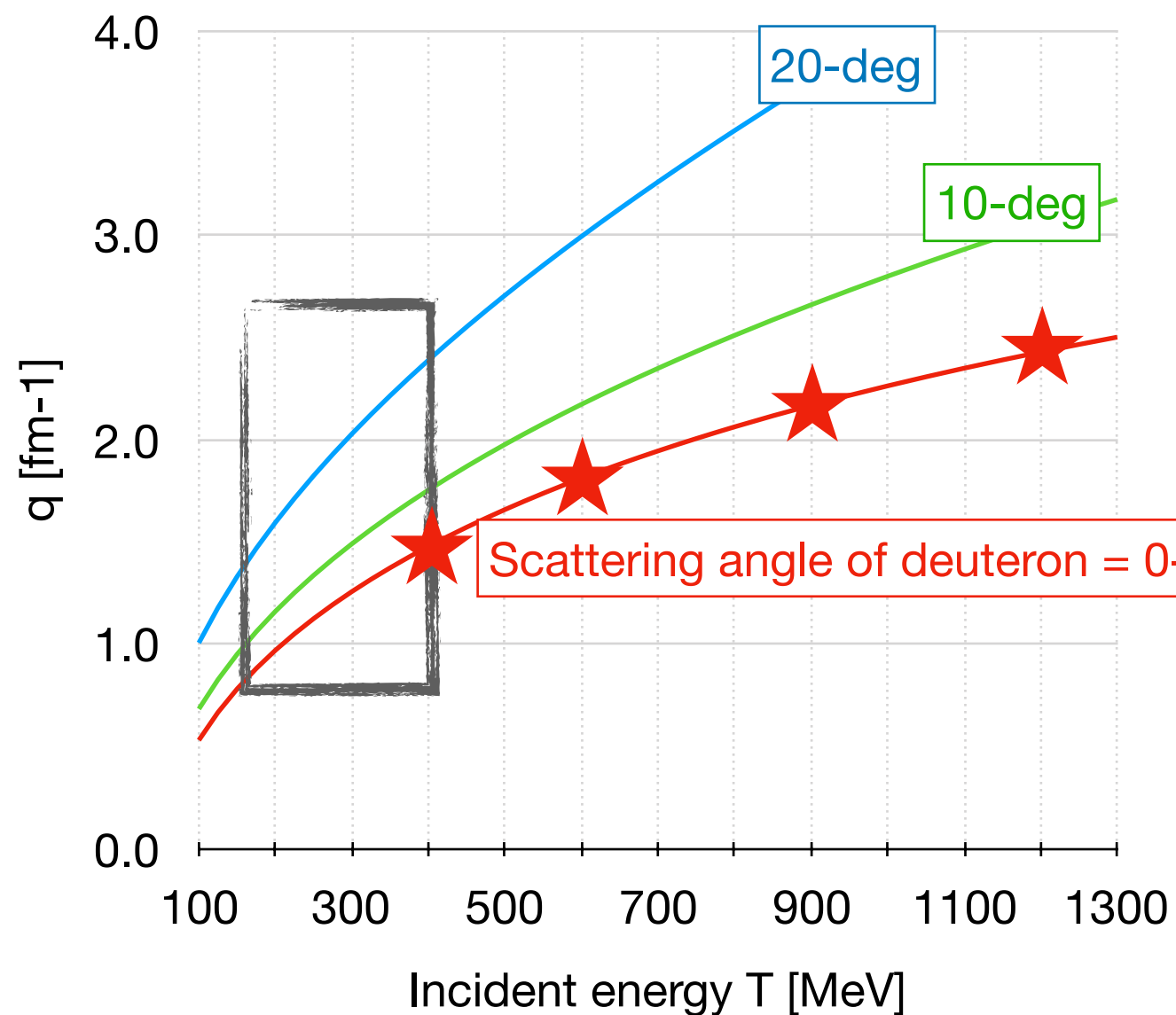
45 MeV: Snelgrove J. L. et al. 1969 Phys. Rev.187(4), 1246–1258



Due to $\longrightarrow$ Complexity of reaction mechanism?

392, 198 MeV: Ong HJ et al., PLB 725, 277(2013)

45 MeV: Snelgrove J. L. et al. 1969 Phys. Rev. 187(4), 1246–1258

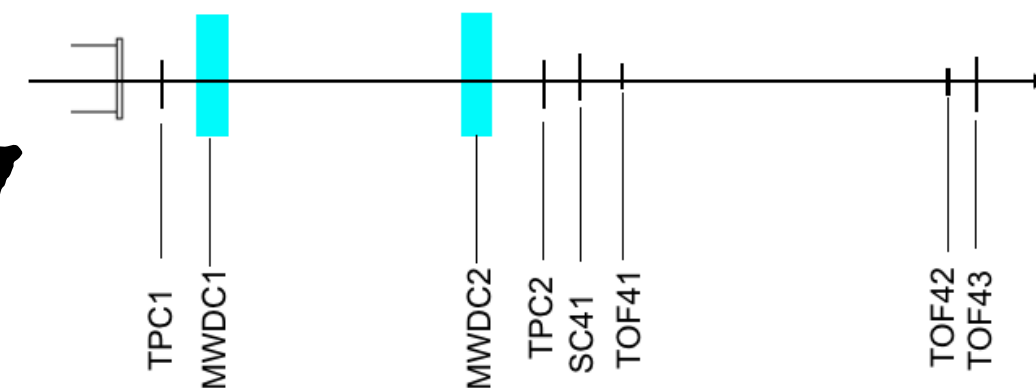
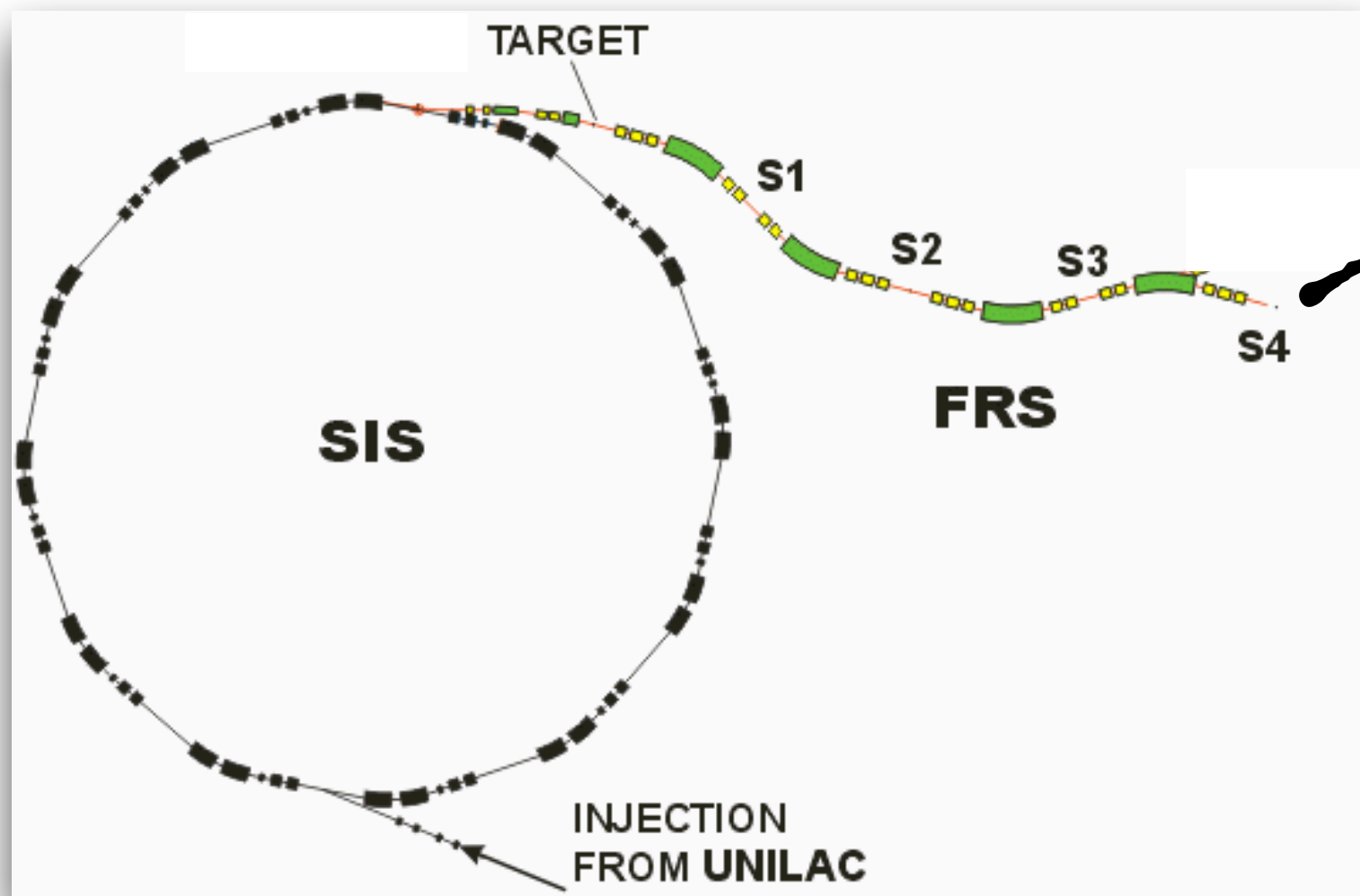


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Schematic layout @S4 focal plane

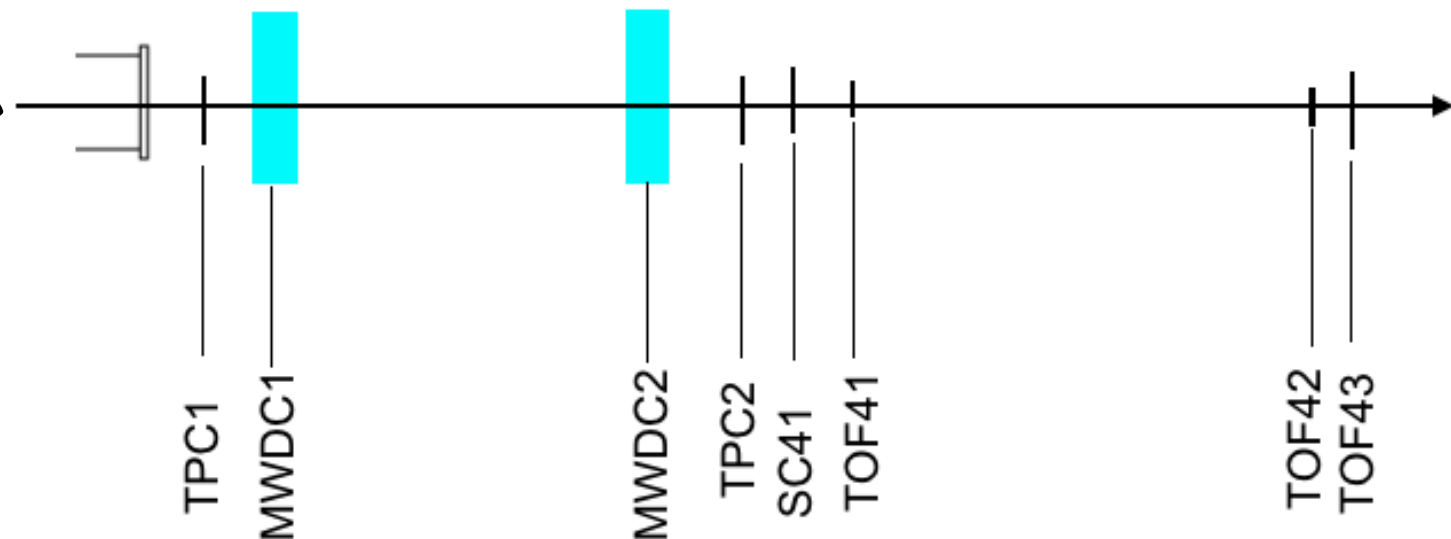
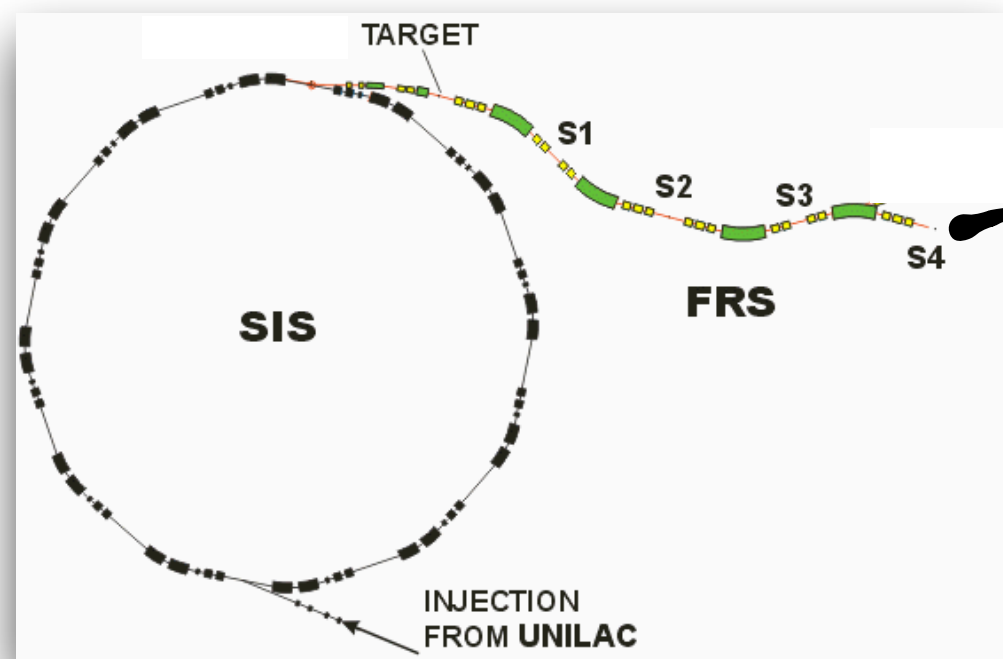
MWDC: multi-wire drift-chamber
TPC: time projection chamber
SC: scintillator
TOF: scintillator for time-of-flight measurement

High resolution mode

Momentum dispersion ~ 18 cm/%

- ▶ $^{16}\text{O}(\text{p,d})^{15}\text{O}$
- ▶ Proton beam: 400-1200MeV, $\sim 10^{10}$ /spill
- ▶ 0° measurement ($<1^\circ$)
- ▶ Target: POM (CH_2O)_n 100 & 308 mg/cm²
C 107 & 327 mg/cm²

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Schematic layout @S4 focal plane

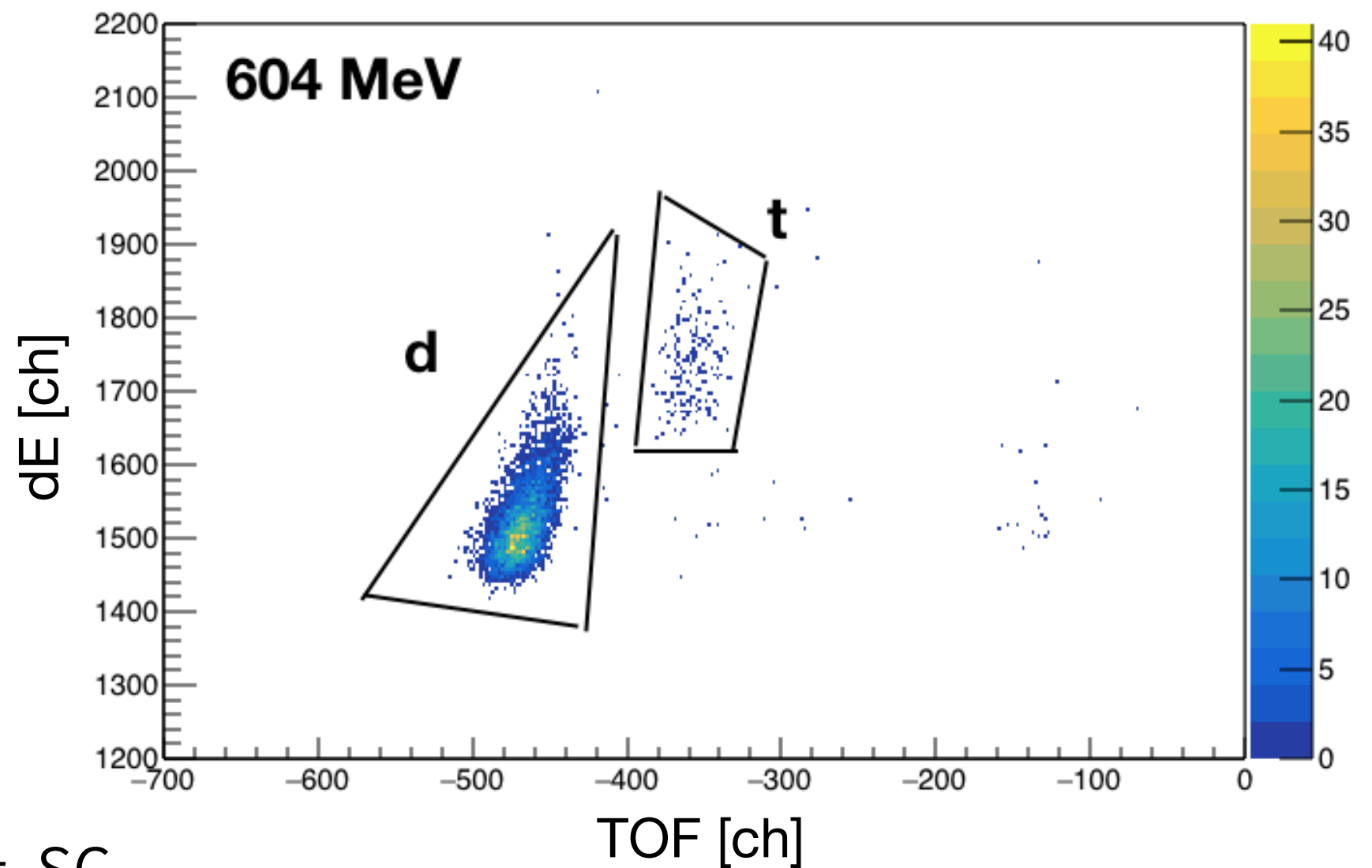
MWDC: multi-wire drift-chamber
TPC: time projection chamber
SC: scintillator
TOF: scintillator for time-of-flight measurement

- ▶ $^{16}\text{O}(\text{p},\text{d})^{15}\text{O}$
- ▶ Proton beam: 400-1200MeV, $q: 1.5\sim 2.4 \text{ fm}^{-1}$
- ▶ 0° measurement ($<1^\circ$)
- ▶ Target: POM $(\text{CH}_2\text{O})_n$ 100 & 308 mg/cm^2
C 107 & 327 mg/cm^2

Particle Identification

Deuterons and tritons are well separated.

$$B\rho - dE - TOF$$



dE: energy deposited at SC

TOF: time-of-flight between SC and PI42 or PI43

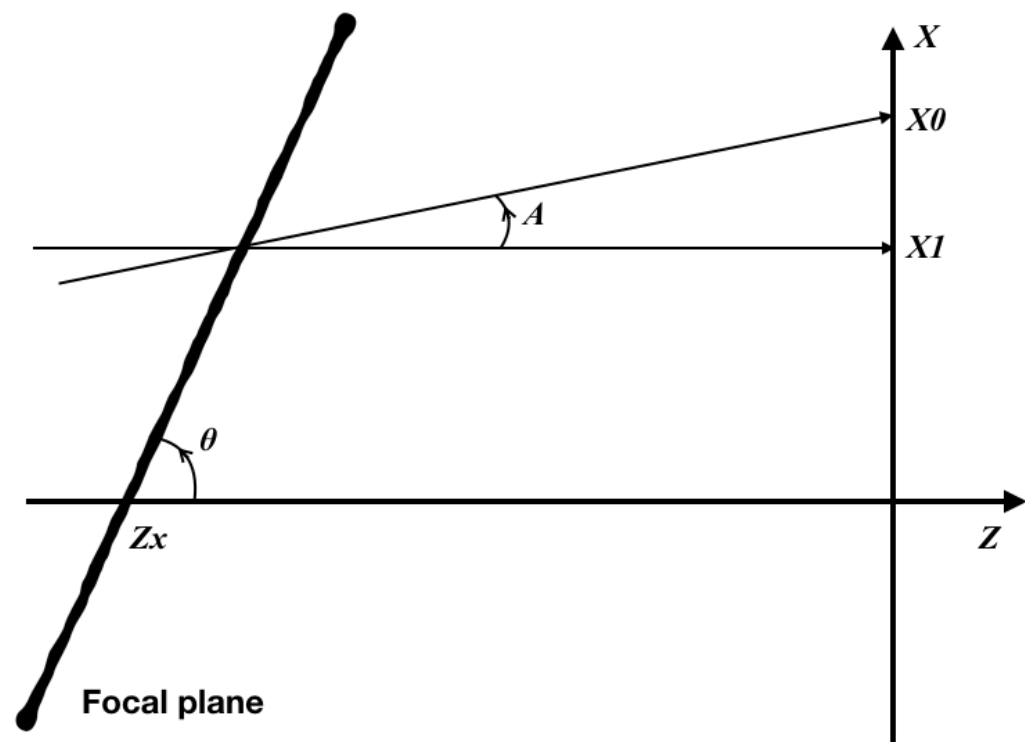
POM target

Tilted focal plane correction

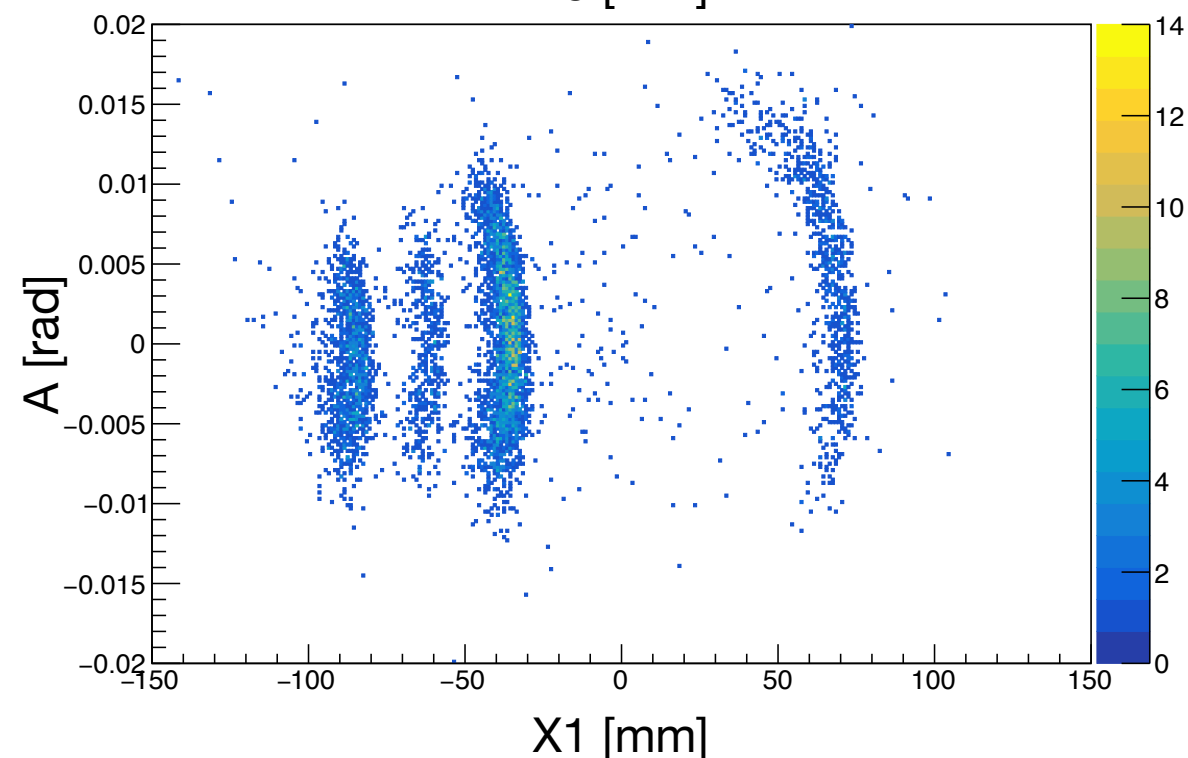
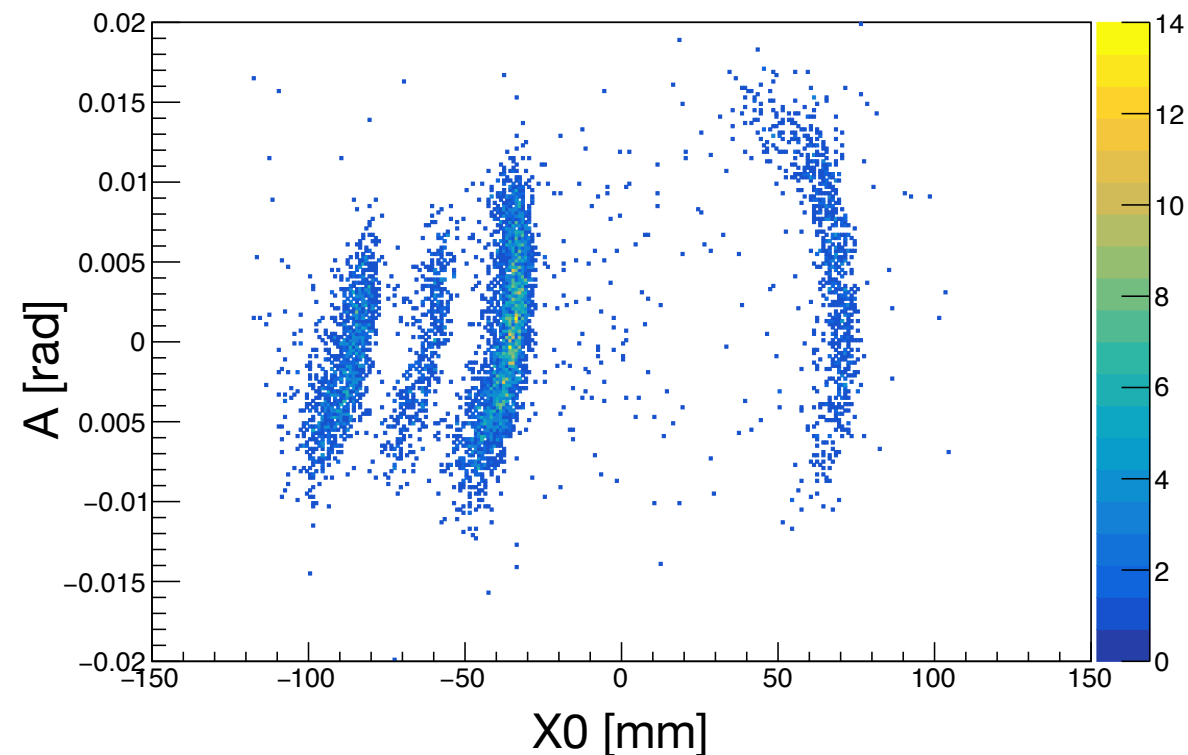
X0: position at Z=0

X1: position at focal plane

$$X1 = \frac{X0 + A \cdot Z_X}{1 - A/\tan\theta}$$

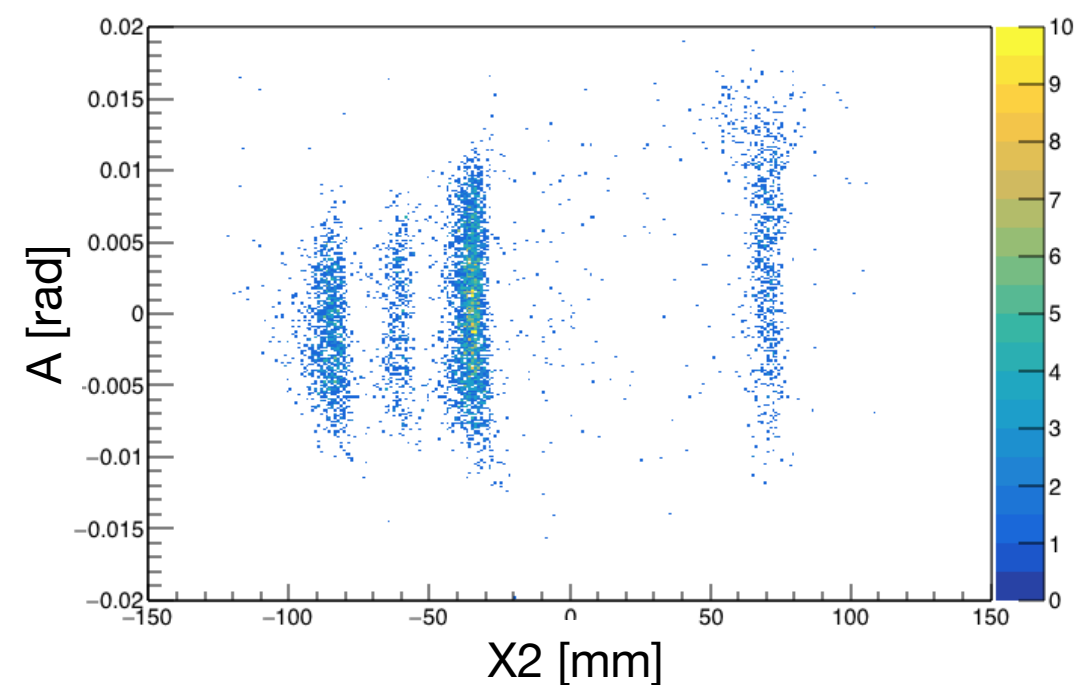
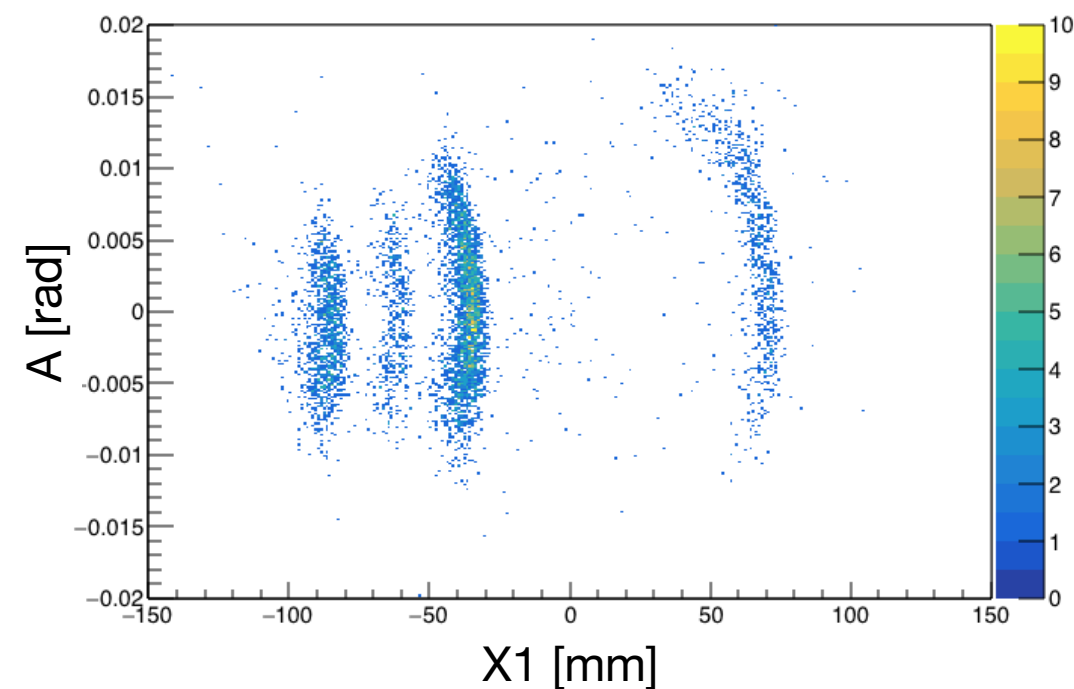
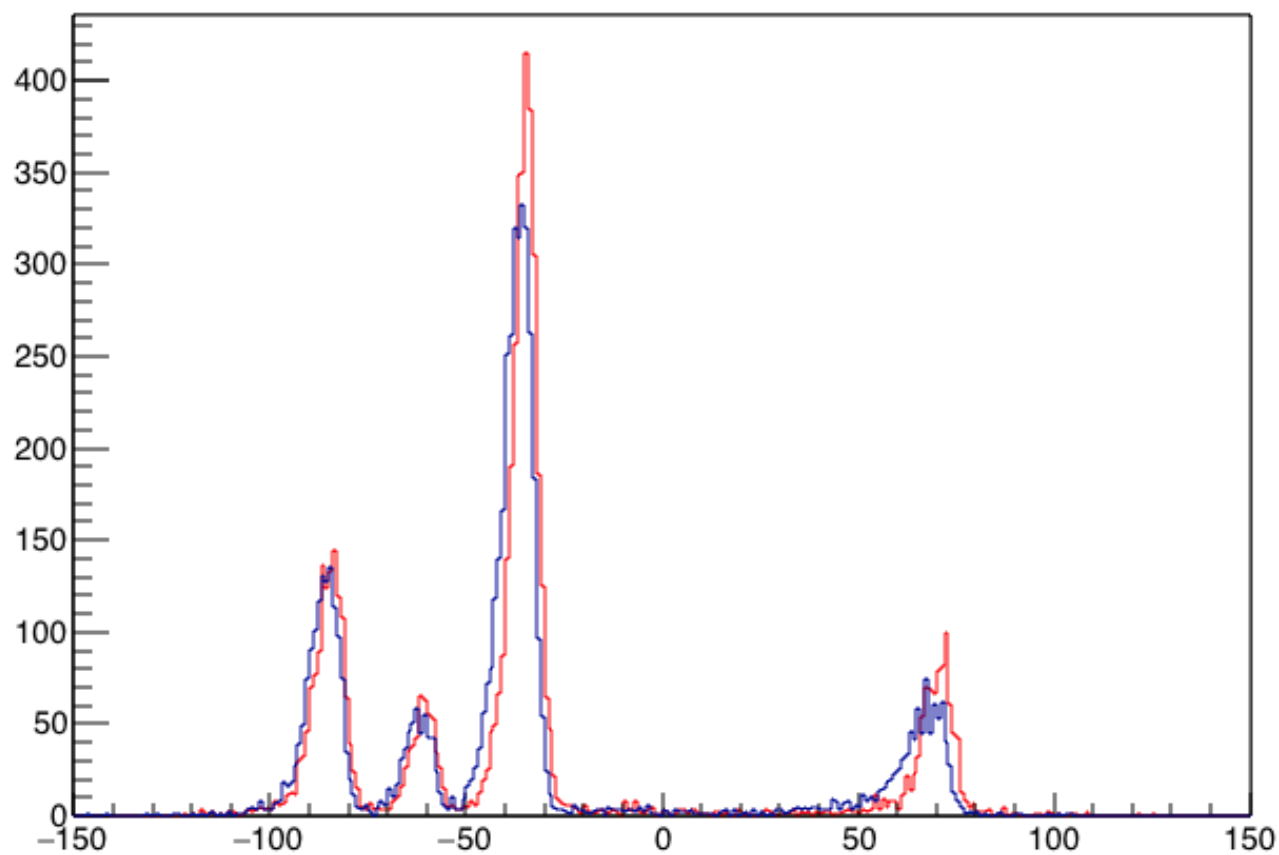


403 MeV, POM

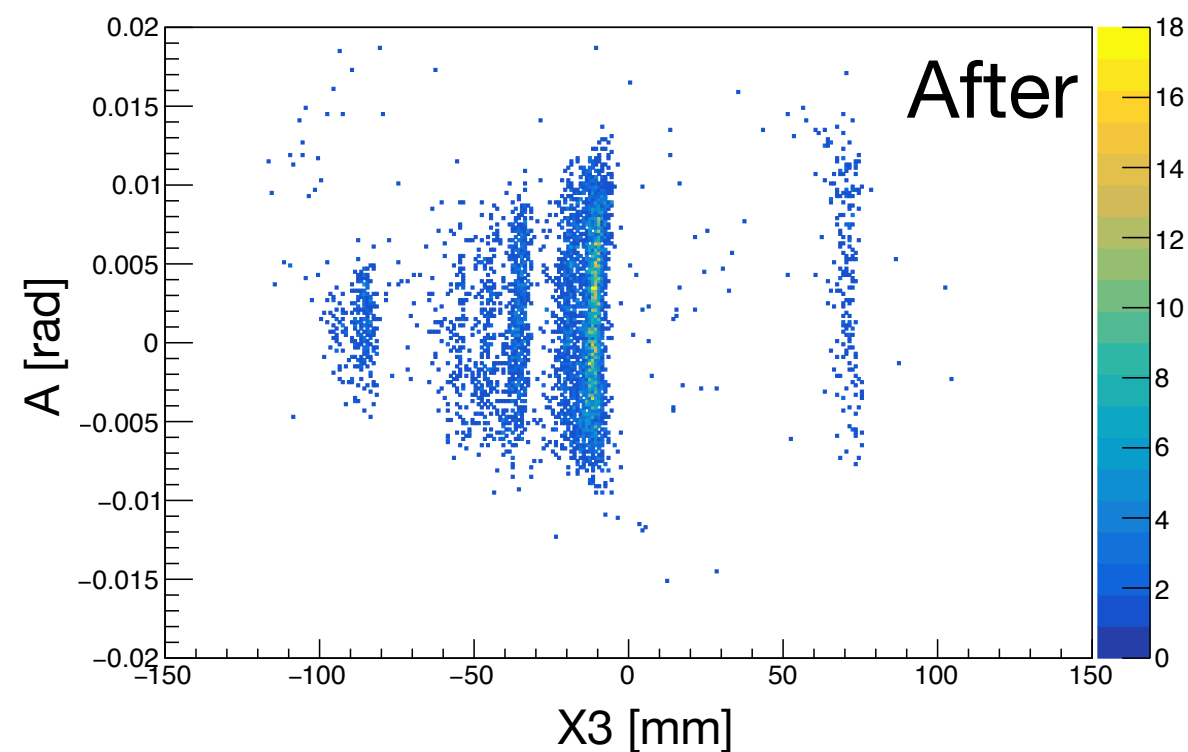
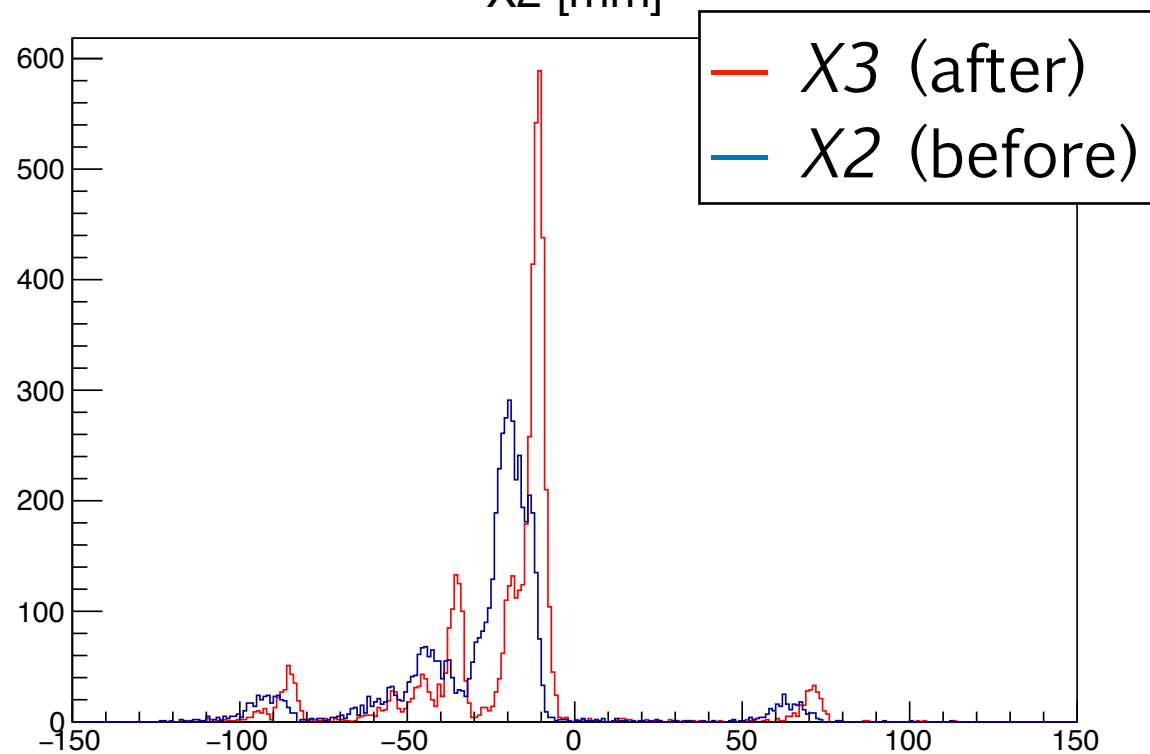
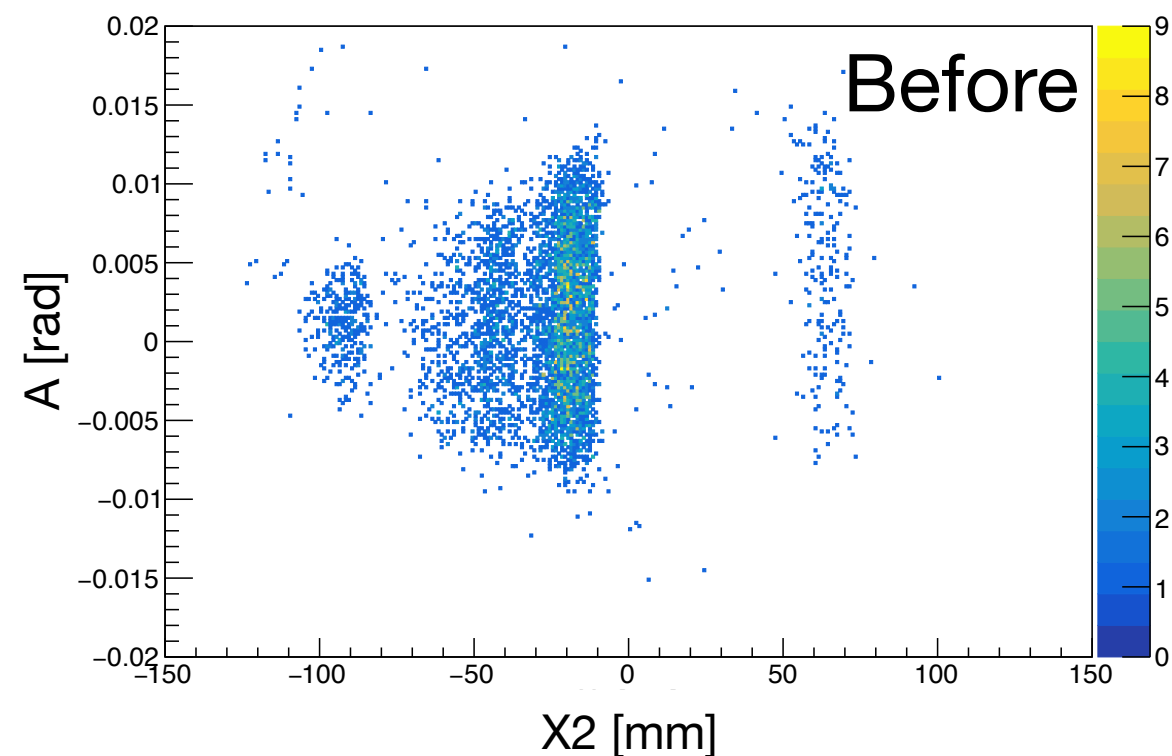
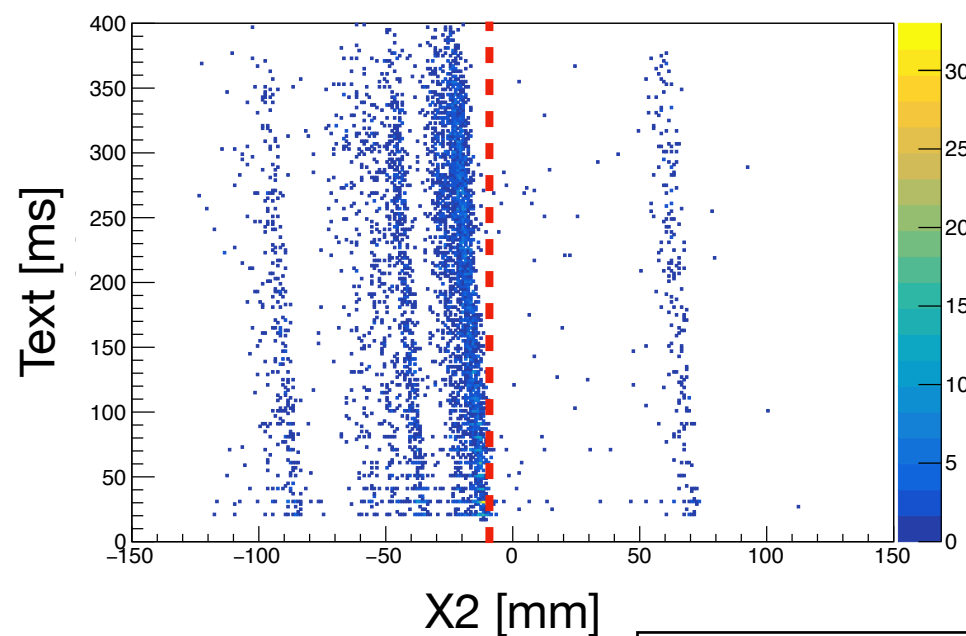


Bending correction

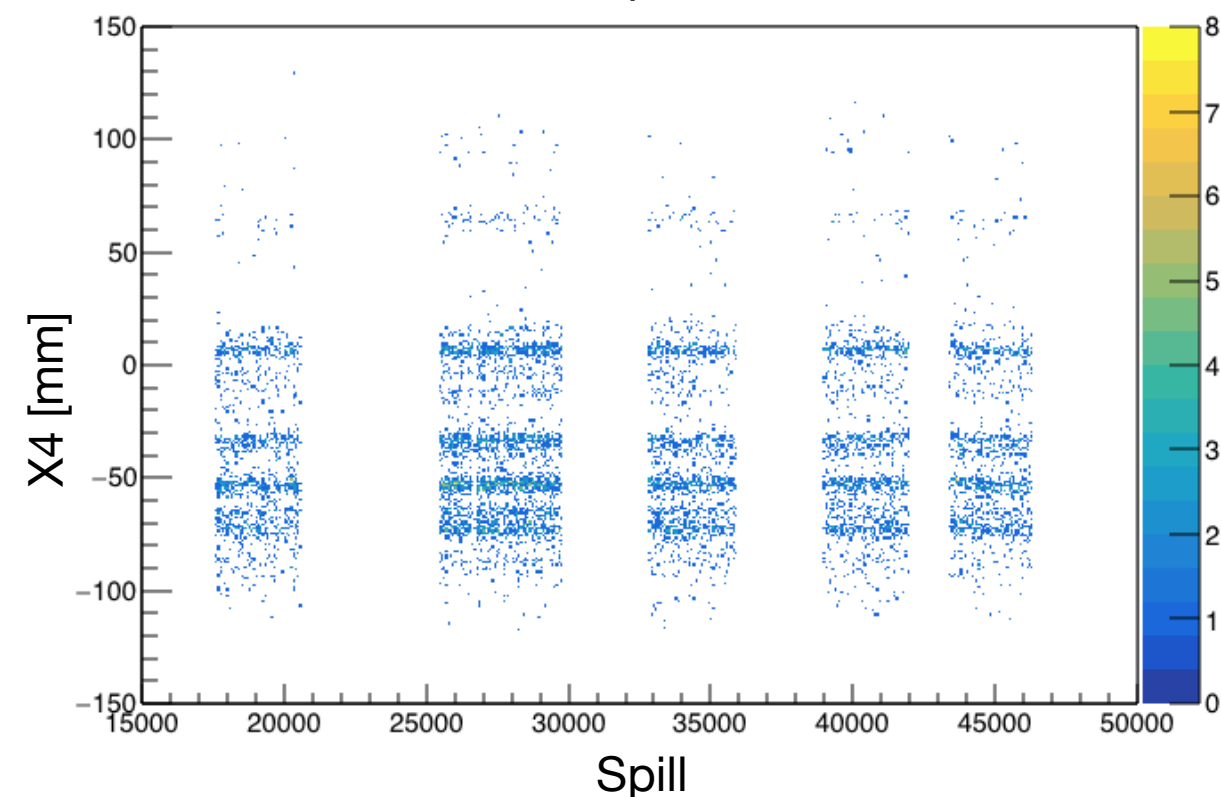
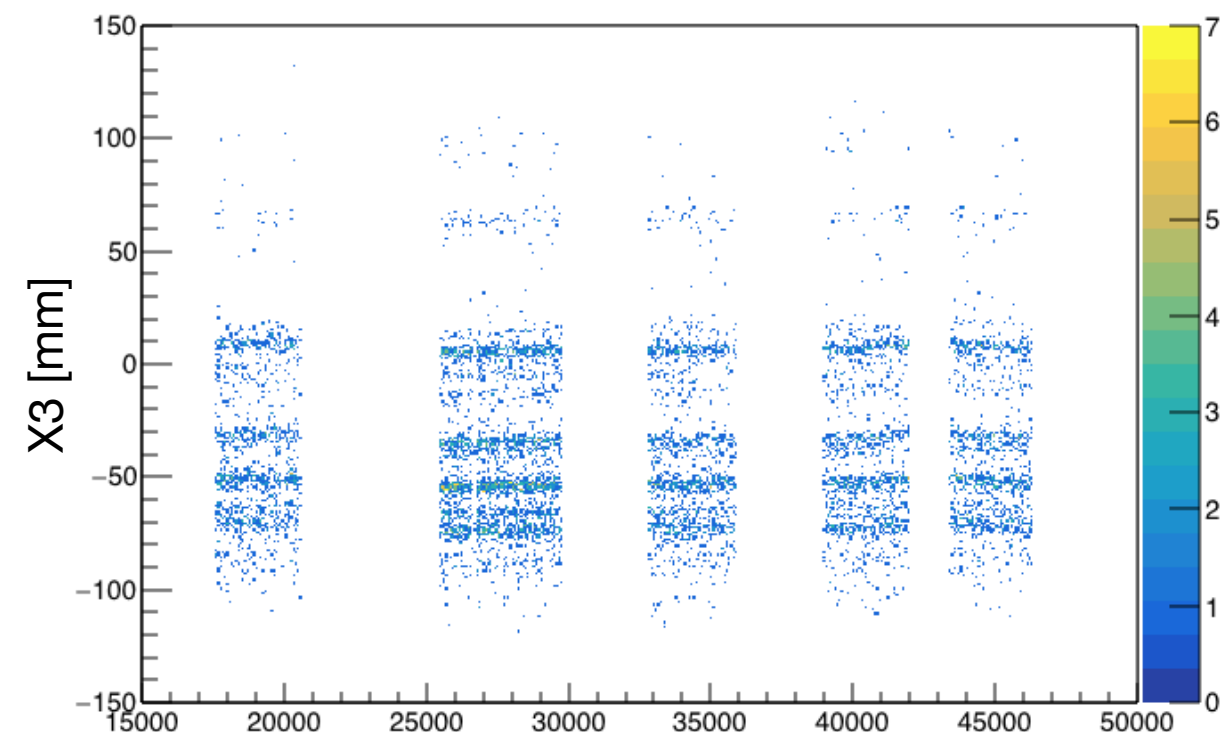
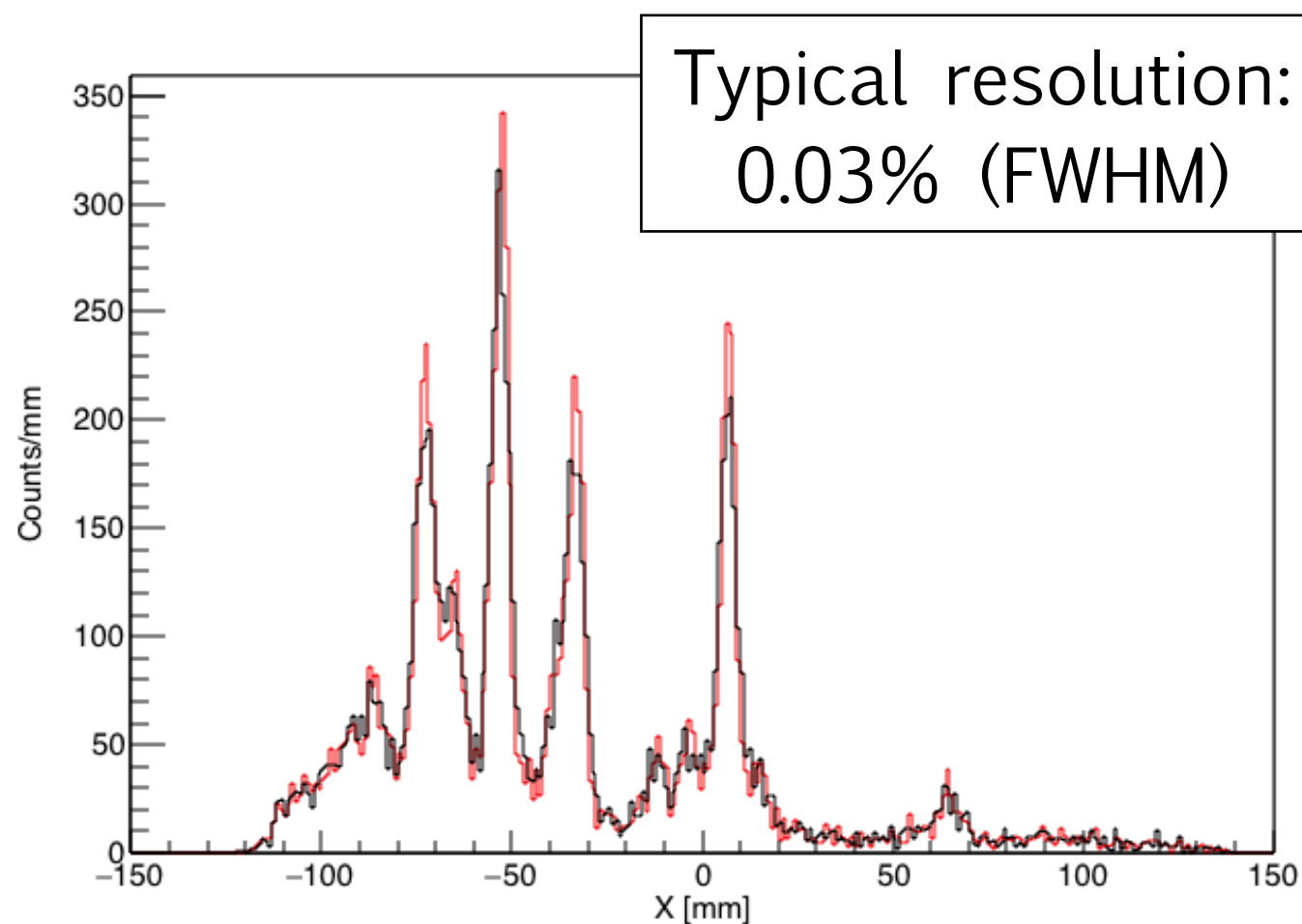
$$X2 = X1 + K_{A^2} \cdot A^2$$



Extraction time correction

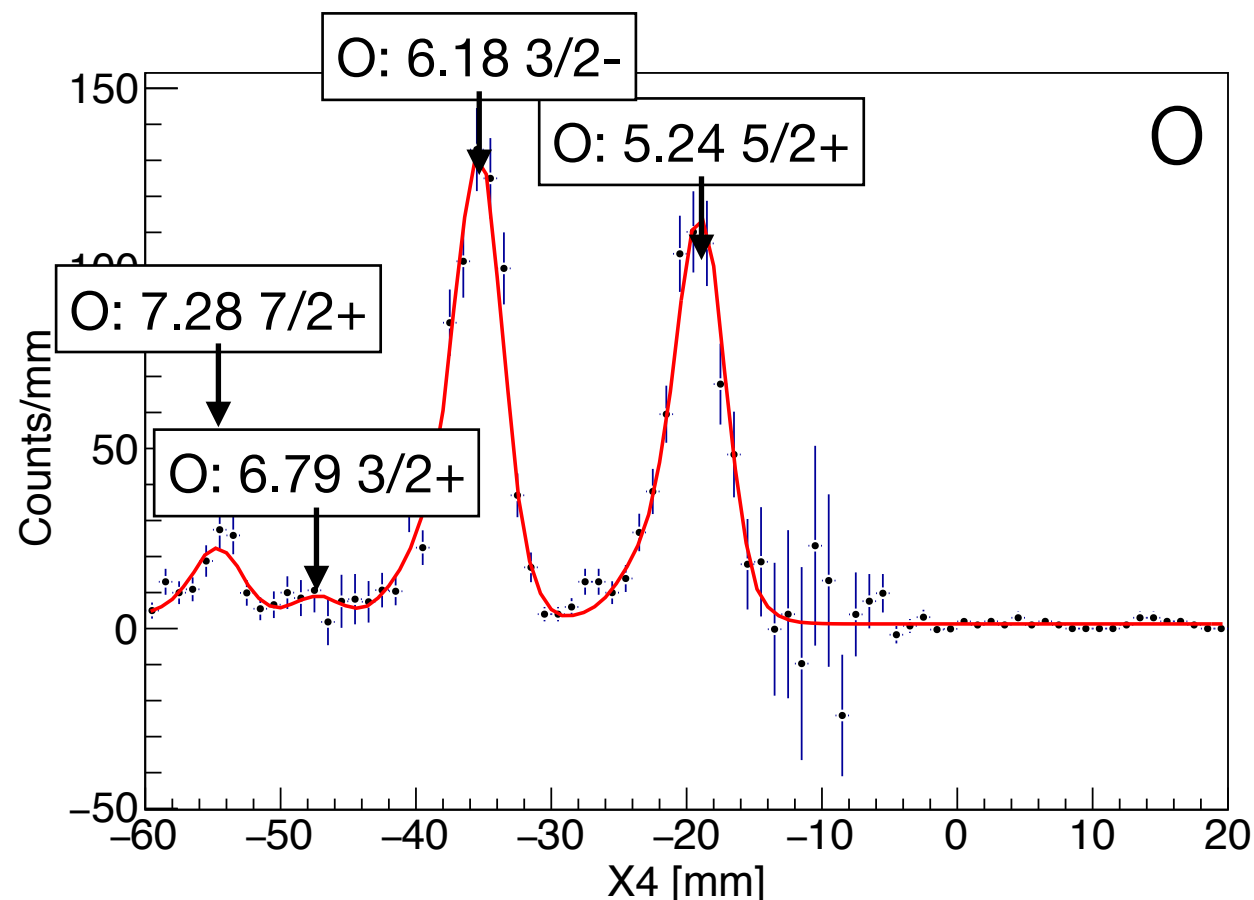
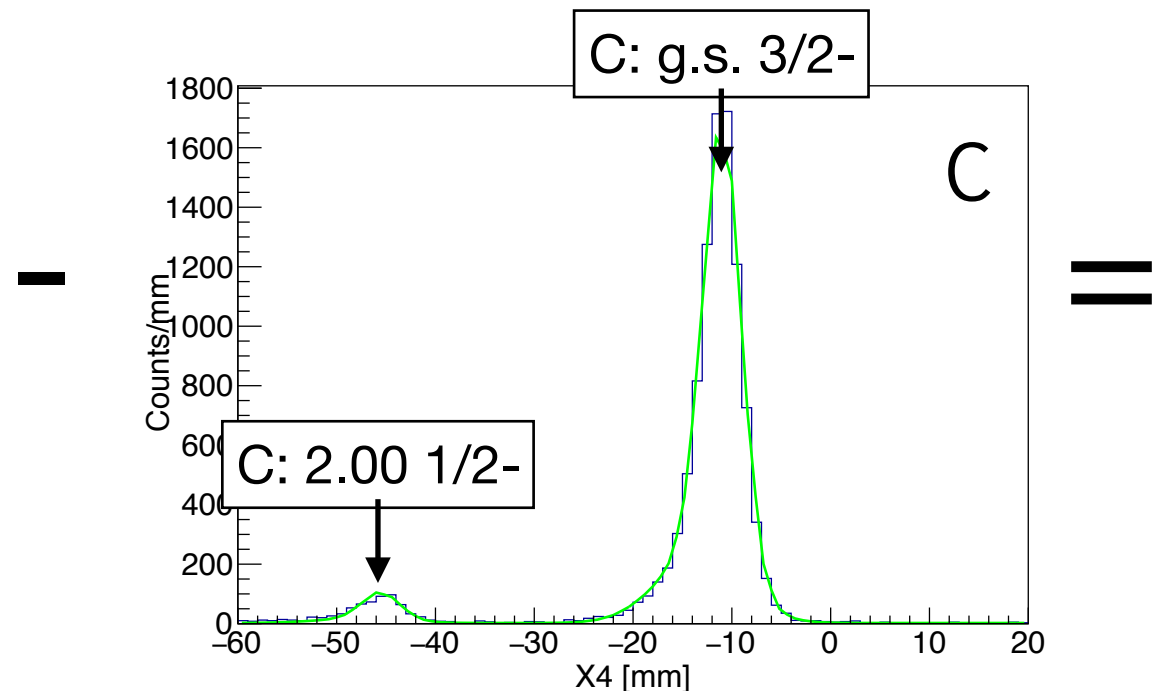
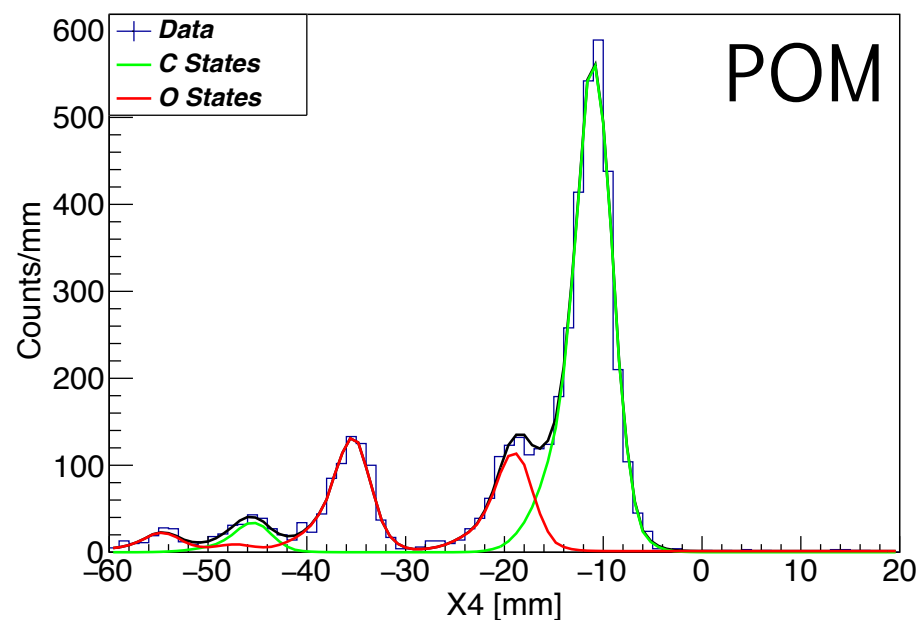


Run stability correction



Subtract C from POM to get O spectrum

@604 MeV as an example



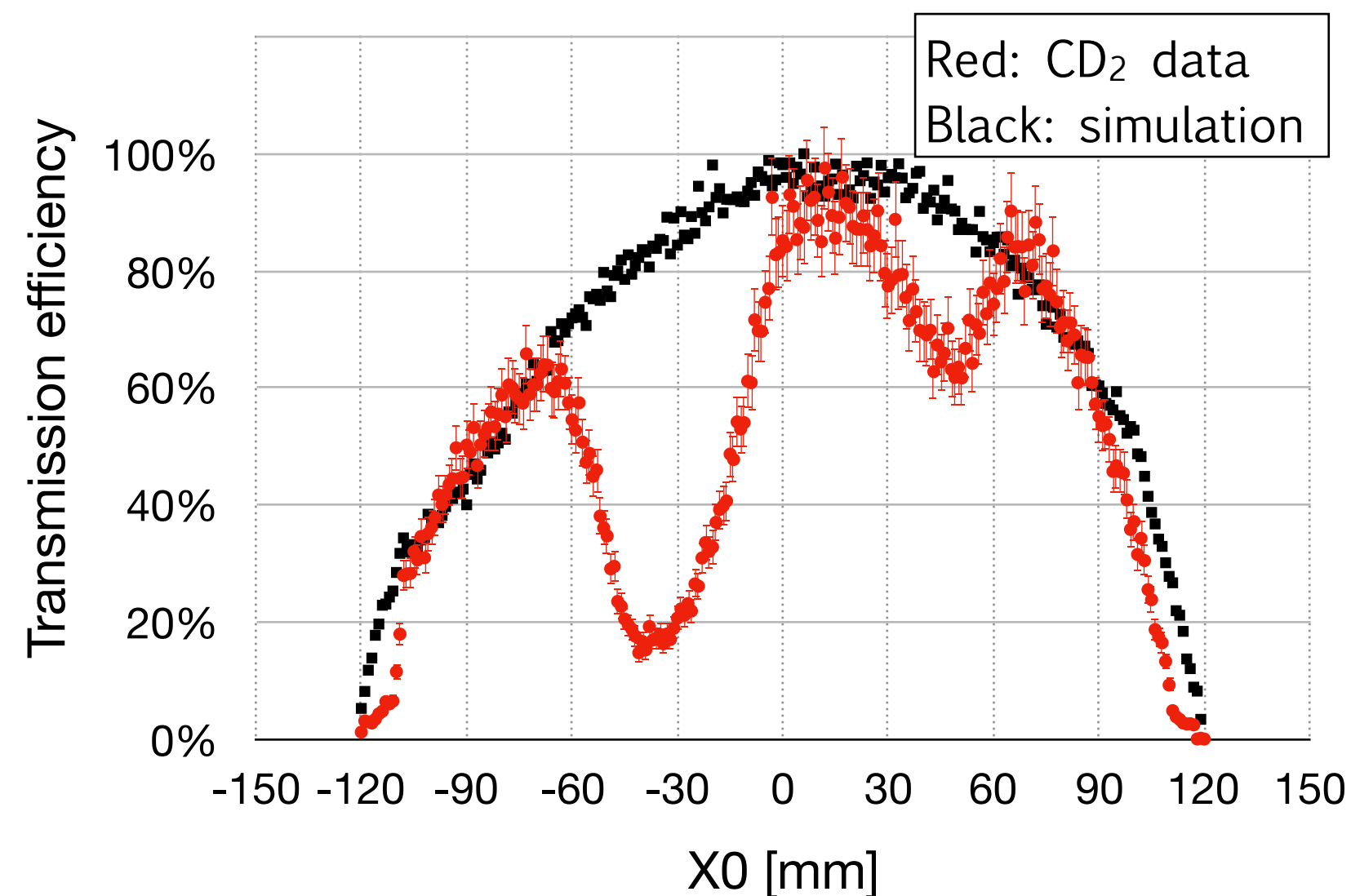
Transmission efficiency of FRS

Transfer matrix calculation using *G/COSY* code

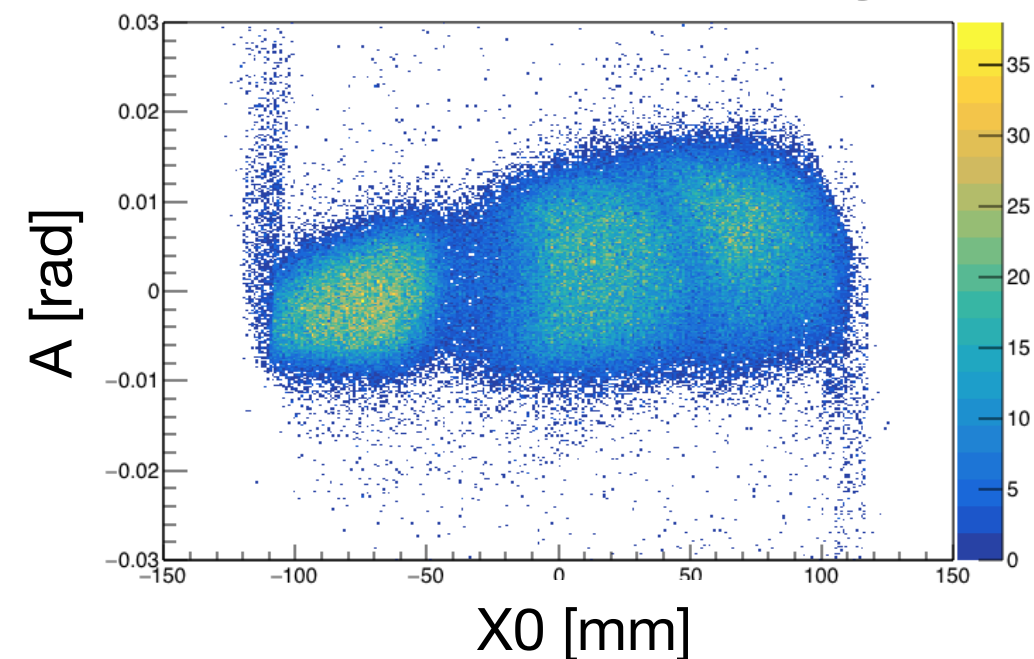
Wollnik H et al. *AIP Conf. Proc.* 177 1988

Monte Carlo simulation using *MOCADI* code

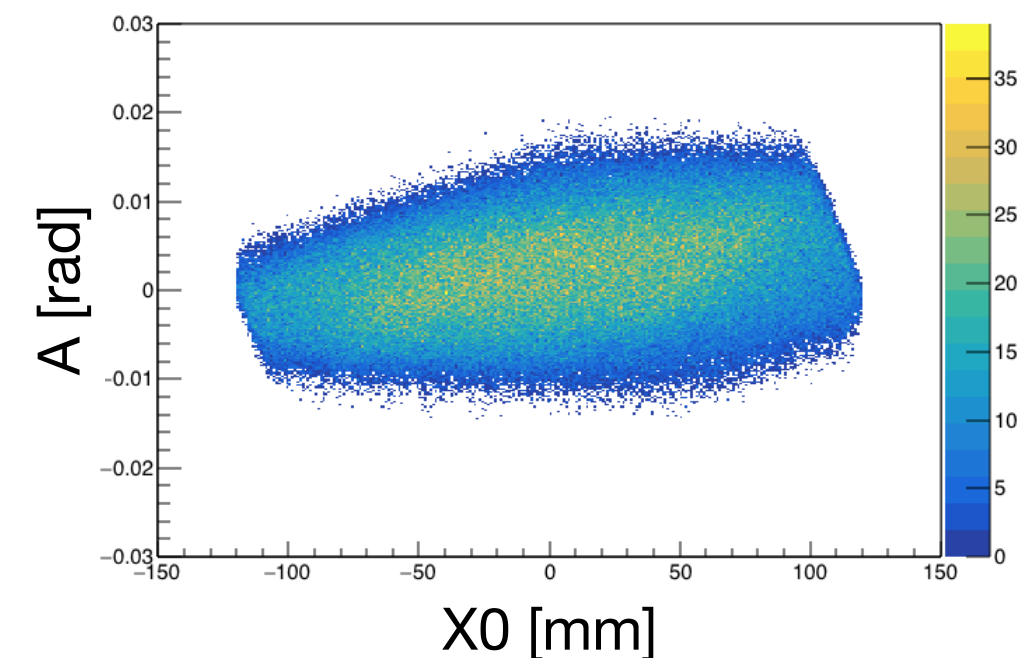
Iwasa N et al. *Nucl. Inst. and Meth. In PRB* 126 1997



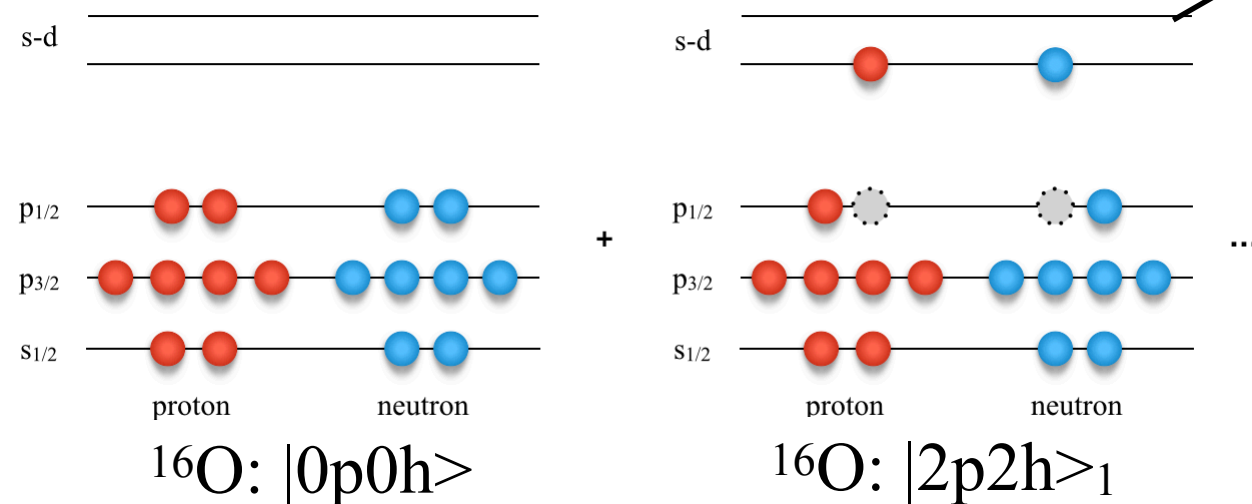
Data with CD2 target



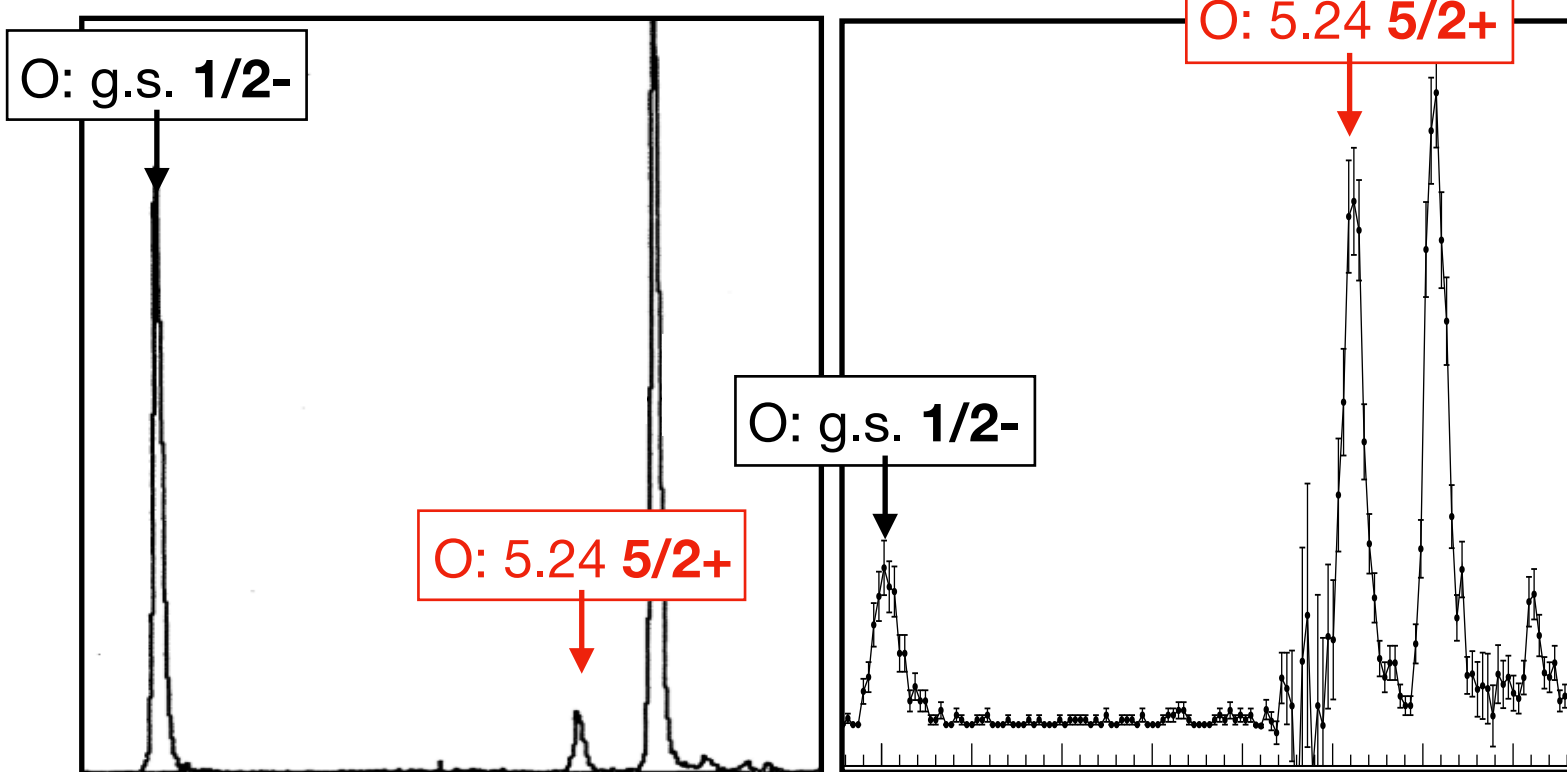
Simulation



Physics understanding

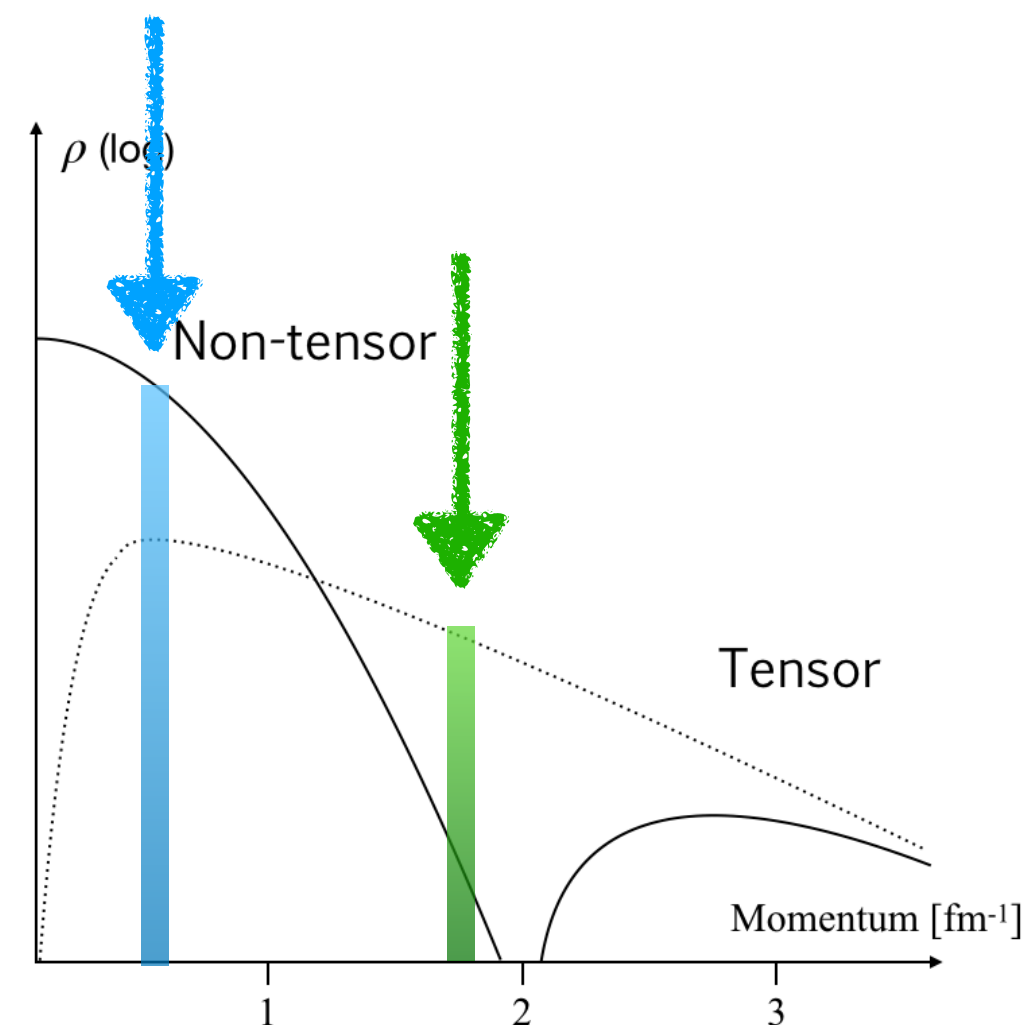


$$|^{16}\text{O}\rangle_{\text{g.s.}} = \alpha|0p0h\rangle + \sum_i \beta_i |2p2h\rangle_i + \dots$$

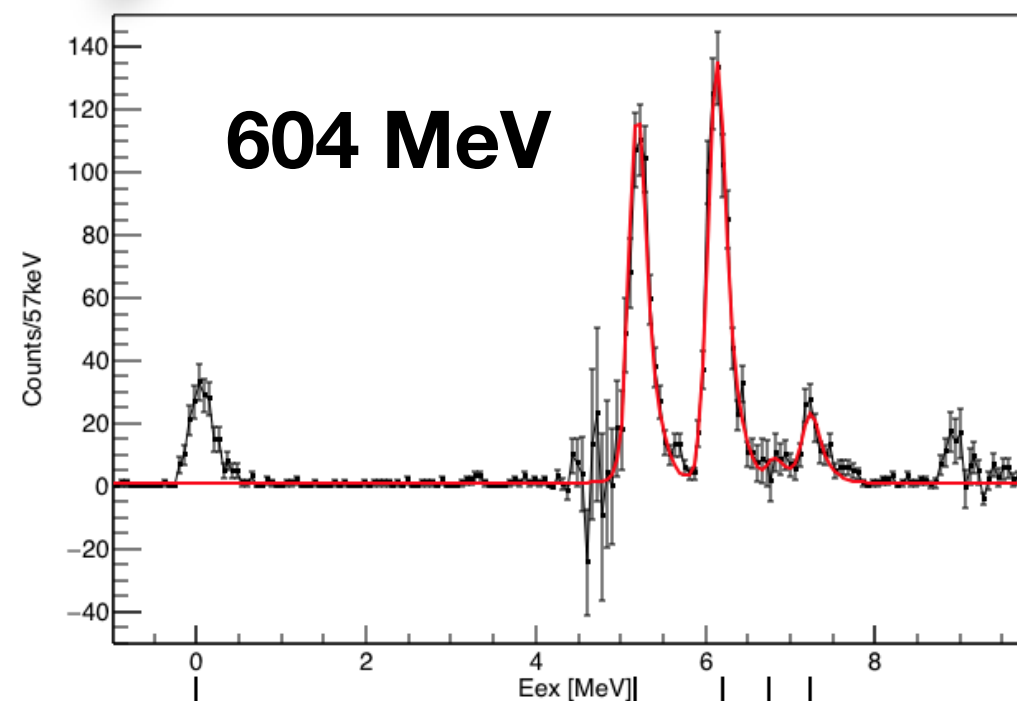


$q=0.5 \text{ fm}^{-1}$

$q=1.8 \text{ fm}^{-1}$



$q=0.5$: Snelgrove J. L. et al. 1969 Phys. Rev.187(4), 1246–1258



$7/2^+$	_____	7.28
$3/2^+$	_____	6.79
$3/2^-$	_____	6.18
$5/2^+$	_____	5.24

$1/2^-$ _____ 0

^{15}O

g.s. $1/2^-$

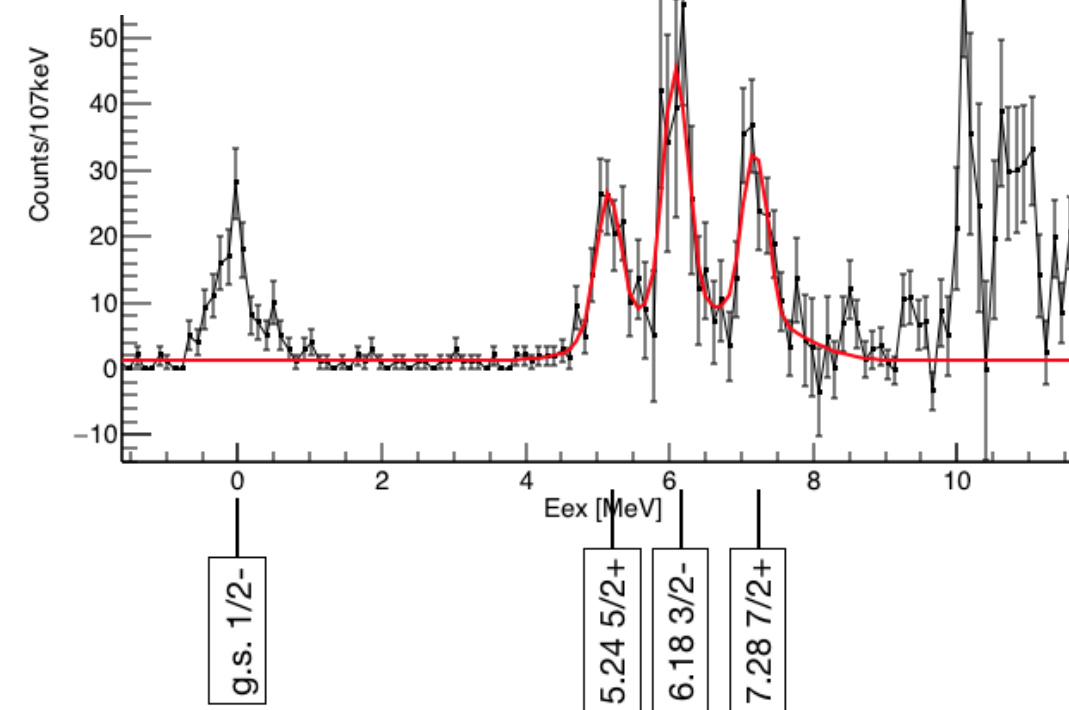
5.24 $5/2^+$

6.18 $3/2^-$

6.79 $3/2^+$

7.28 $7/2^+$

1209 MeV



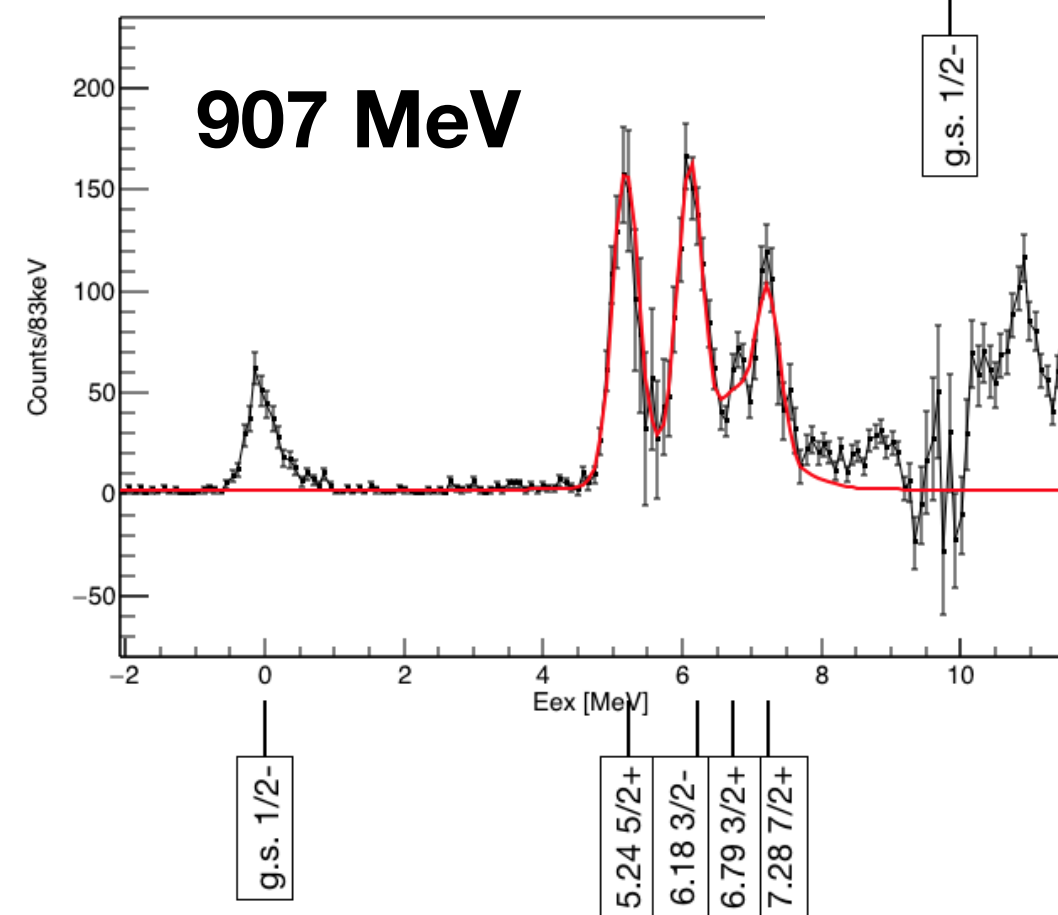
g.s. $1/2^-$

5.24 $5/2^+$

6.18 $3/2^-$

7.28 $7/2^+$

907 MeV



g.s. $1/2^-$

5.24 $5/2^+$

6.18 $3/2^-$

6.79 $3/2^+$

7.28 $7/2^+$

- ☑ We have measured the cross-section of $^{16}\text{O}(\text{p},\text{d})$ reactions with proton beam from 403 to 1209 MeV at GSI. It is the first 0-deg measurement covering 2-fm^{-1} momentum transfer region.
- ☑ The different tendencies of cross-section ratios show the existence of high-momentum component ($\sim 2\text{ fm}^{-1}$) inside the nuclei, which arises from tensor interactions.
- ☑ Present results (0°) confirm the enhancement observed at previous experiments(at finite angle), showing that reaction mechanism has small effect compared with tensor interactions.
- ☑ Other positive parity excited states are observed at large momentum transfer, indicating other 2p2h configurations in the wave function of ^{16}O ground state.

X. Wang, H.J. Ong, S. Terashima, Y. Ayyad, J. Benlliure, H. Fujioka, H. Geissel, J. Gellanki, C.L. Guo, E. Haettner, M.N. Harakeh, R.S. Hayano, C. Hornung, K. Itahashi, N. Kalantar-Nayestanaki, R. Kanungo, R. Knoebel, K. Miki, I. Mukha, T. Myo, T. Nagae, T. Neff, T. Nishi, C. Nociforo, K. Ogata, D.Y. Pang, S. Pietri, A. Prochazka, C. Rappold, M.P. Reiter, J.-L. Rodriguez-Sanchez, C. Scheidenberger, H. Simon, B. Sitar, P. Strmen, B.H. Sun, K. Suzuki, I. Szarka, M. Takechi, Y. Tanaka, I. Tanihata, H. Toki, H. Weick, J.S. Winfield, X.D. Xu, D. Yamakami, J.W. Zhao

RCNP, Osaka University, Michigan State University/NSCL,
University Santiago de Compostela, University Giessen, Kyoto University,
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Beihang University, University of Tokyo, RIKEN Nishina Center,
Saint Mary's University, Osaka Institute of Technology, Comenius University Bratislava,
Stefan Meyer Institute, Niigata University

Thanks for your attention!