

14th ITP/CAS-BLTP/JINR Joint Workshop on
Physics of Strong Interacting Systems
Oct. 18-23, 2026, Nanjin

Vortex nucleon-nucleon scattering

Jinniu Hu

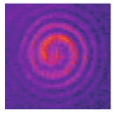
School of Physics, Nankai University

J. Hu, Y. Zhang, and H. Shen, Phys. Rev. C 114(2026)034012

Optical vortices

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2011 — Generalized laws of reflection/refraction were proposed and OAM was tailored in metasurface.



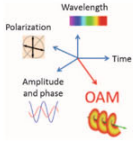
Science 334, 333

2012 — Integrated compact vortex beam emitters were produced.



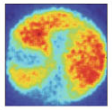
Science 338, 363

2012-2013 — Terabit optical communication was realized using OAM in free space and fibre.



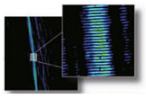
Nat. Photon. 6, 488
Science 340, 1545

2015 — Neutron vortex beams carrying OAM were produced.



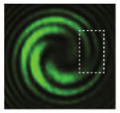
Nature 525, 504

2016 — Extreme OAM states over 10000 $\hbar$ were generated.



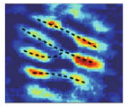
PNAS 113(48), 13642

2017 — Arbitrary SAM-to-OAM conversion was realized via metasurface.



Science 358, 896

2017 — Tunable OAM in high-harmonic generation was realized.



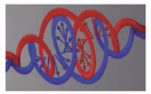
Nat. Commun. 8:14970
Nat. Commun. 8:14971

2018 — Ultra-broadband on-chip OAM emitter was designed and used for communications.



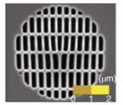
Light: Sci. Appl. 7, 18001

2018 — Quantum Entanglement of SAM and OAM was realized in metamaterials.



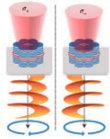
Science 361, 1101

2019 — Soft X-ray vortex beam was generated using diffractive optics.



Nat. Photon. 13, 205–209

2019 — Vortex chirality was controlled in microlasers.

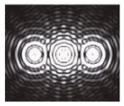


Nat. Photon. 13, 283–288

2010 2011 2012 2013 2014 2015 2016 2017 2018 2019

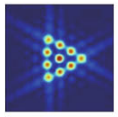
2009

2010 — Electron vortex beams carrying OAM were produced.



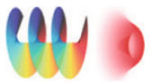
Nature 467, 301

2010 — Optical lattice in triangular aperture diffraction of OAM beams was unveiled.



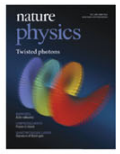
Phys. Rev. Lett. 105, 053904

2008 — Barreiro et al. used OAM in quantum communication beating the capacity limit.



Nat. Phys. 4, 282

2007 — Molina-Terriza et al. reviewed the properties of twisted photons.



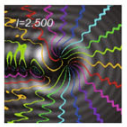
Nat. Phys. 3, 305

2006 — Tamburini et al. showed the effect of superdiffraction limit in OAM beams.



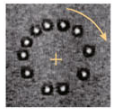
Phys. Rev. Lett. 97, 163903

2004 — Non-integer OAM vortices were proposed and observed.



New J. Phys. 6, 71

2003 — Grier reviewed the optical tweezers and spanner using vortex beams.



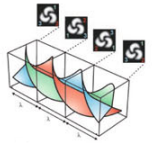
Nature 424, 810

2002 — MacDonald et al. manipulated the 3D trapped structures by vortex beams.



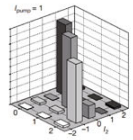
Science 296, 1101

2001 — Paterson et al. rotated micro-particles trapped by vortex beams.



Science 292, 912

2001 — Zeilinger's group realized the quantum entanglement of OAM states.



Nature 412, 313

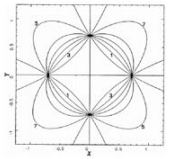
2008 2007 2006 2005 2004 2003 2002 2001 2000

1989 — Coullet et al. first proposed the concept of optical vortices.



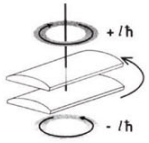
Opt. Commun. 73(5), 403

1991 — Brambilla et al. studied the formation of phase-singularity.



Phys. Rev. A 43(9), 5090

1992 — Allen et al. showed that vortex beams contain OAM and how to generate them.



Phys. Rev. A 45(11), 8185

1995 — The OAM of vortex beams was used to rotate particles with optical tweezers.



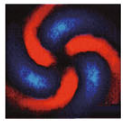
Phys. Rev. Lett. 75(5), 826

1996 — The group of Padgett observed the second-harmonic generation of OAM light.



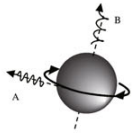
Phys. Rev. A 54(5), R3742

1997 — Soskin et al. studied the topological charge in vortex beam propagation.



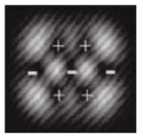
Phys. Rev. A 56(5), 4064

1998 — Courtial et al. discovered the rotational Doppler effect of vortex beams.



Phys. Rev. Lett. 81(22), 4828

1999 — Scheuer and Orenstein generated the vortices crystals in semiconductor microcavities.



Science 285, 230

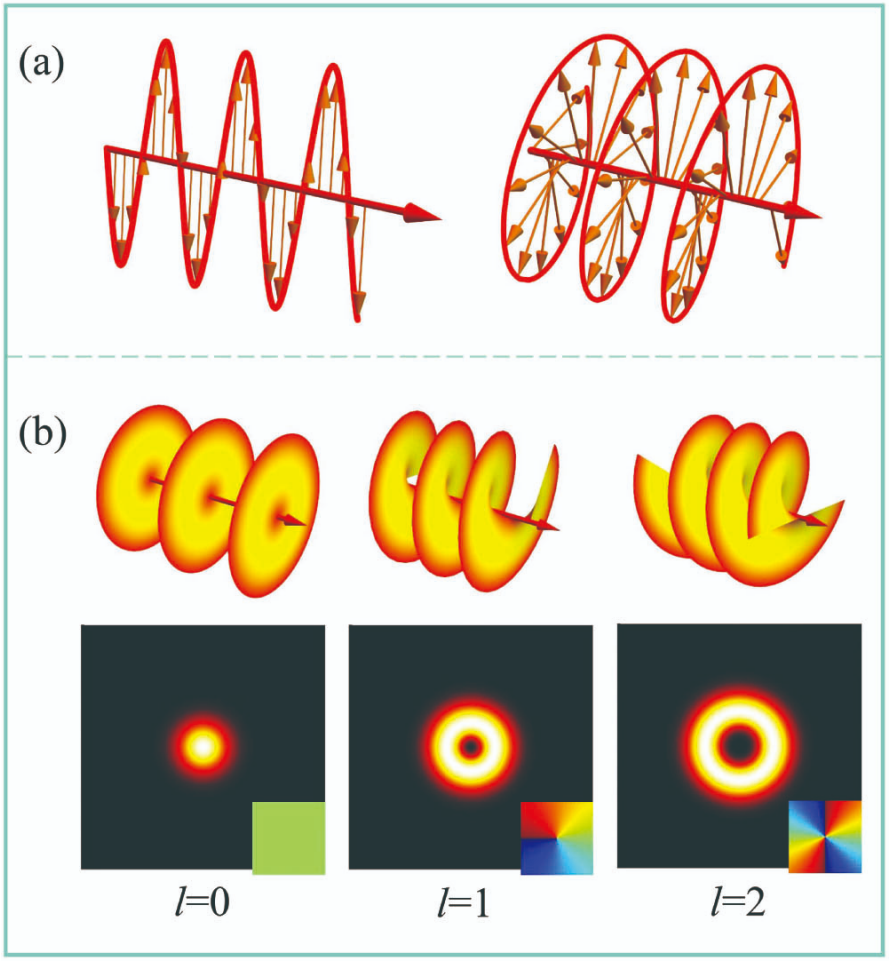
1999

1989 1990 1991 1992 1993 1994 1995 1996 1997 1998

Shen et al. Light: Science & Applications 8(2019)90

Optical vortices

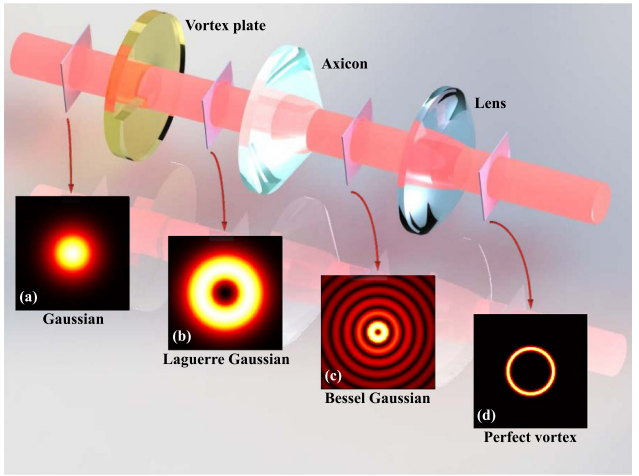
Linearly polarized light carries no spin angular moment (SAM)



Circularly polarized light

$$E(r,\phi,z) \propto u(r,z)e^{il\phi}.$$

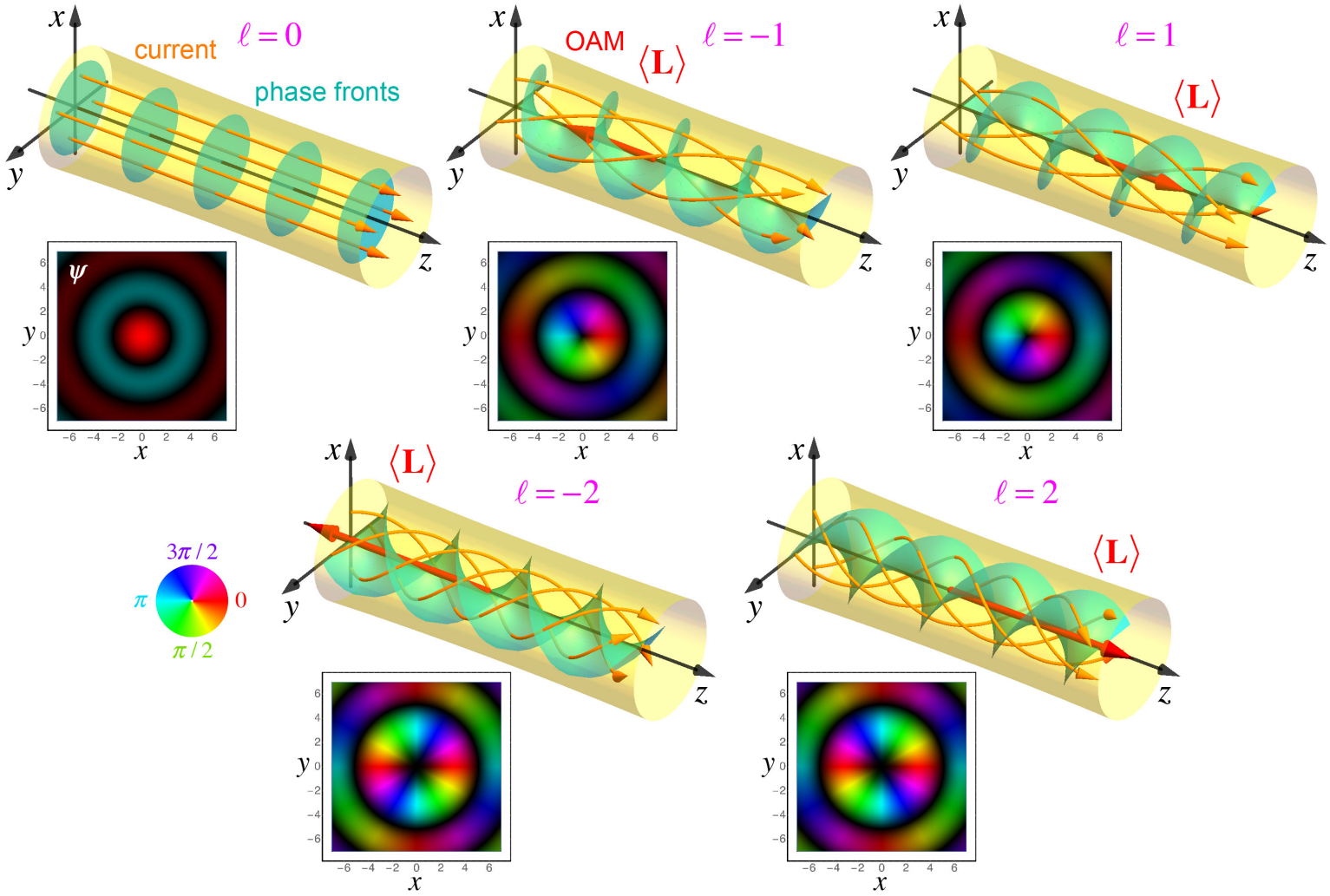
$$e^{il\phi} \iff L_z = \ell\hbar\,.$$



Wavefront, intensity, and corresponding phase distribution of vortex beams with topological charge of l= 0, 1, 2.

Bai et al. Chin. Opt. Lett. 20(2022)012601

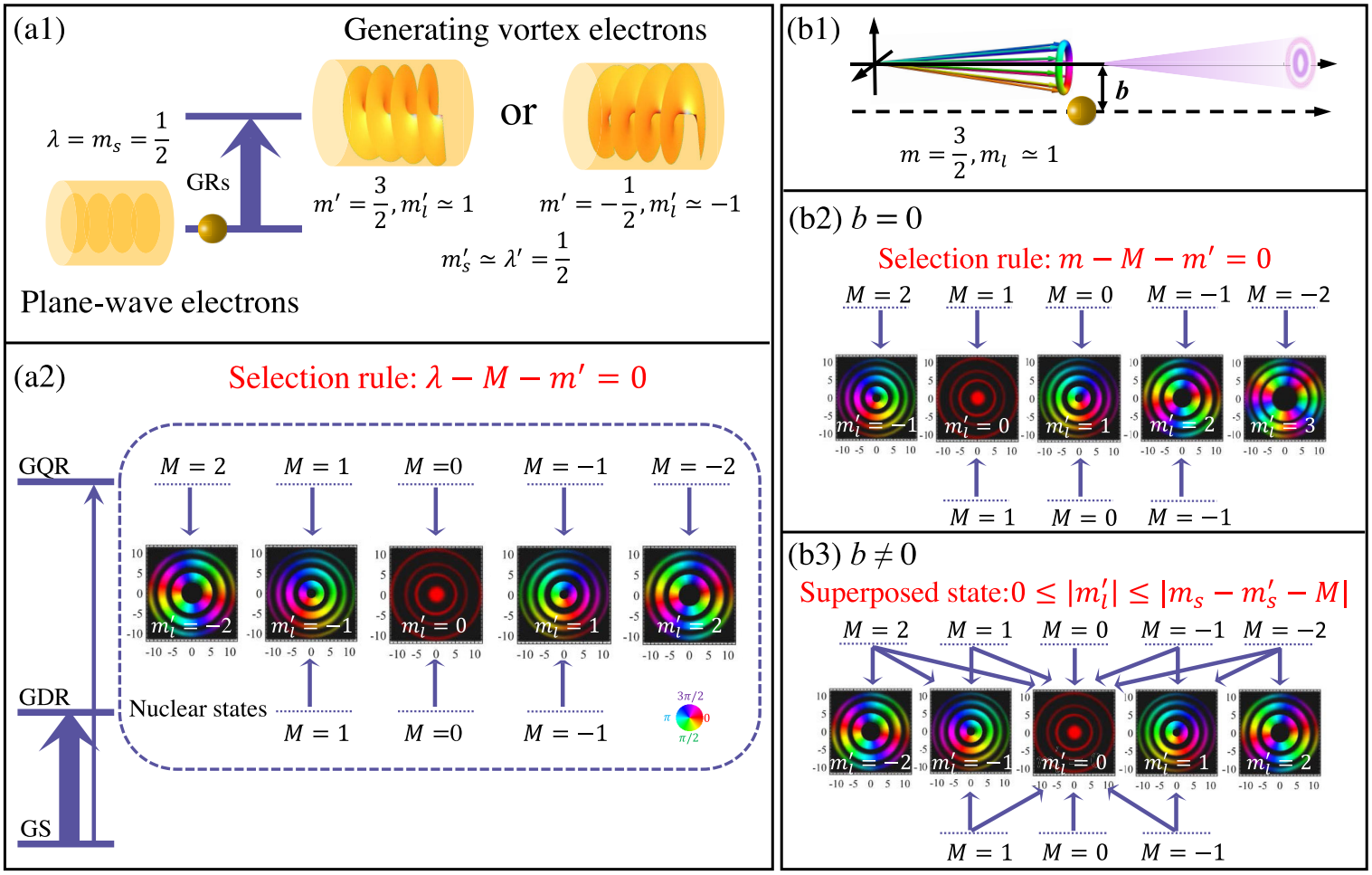
Electron vortices



Bliokh et al. Phys. Rep. 690(2017)1

Lloyd et al. Rev. Mod. Phys. 89(2017)035004

Vortex electron interact with nuclei



Z. W. Li, et al, Phys. Rev. Lett. 134(2025) 052501

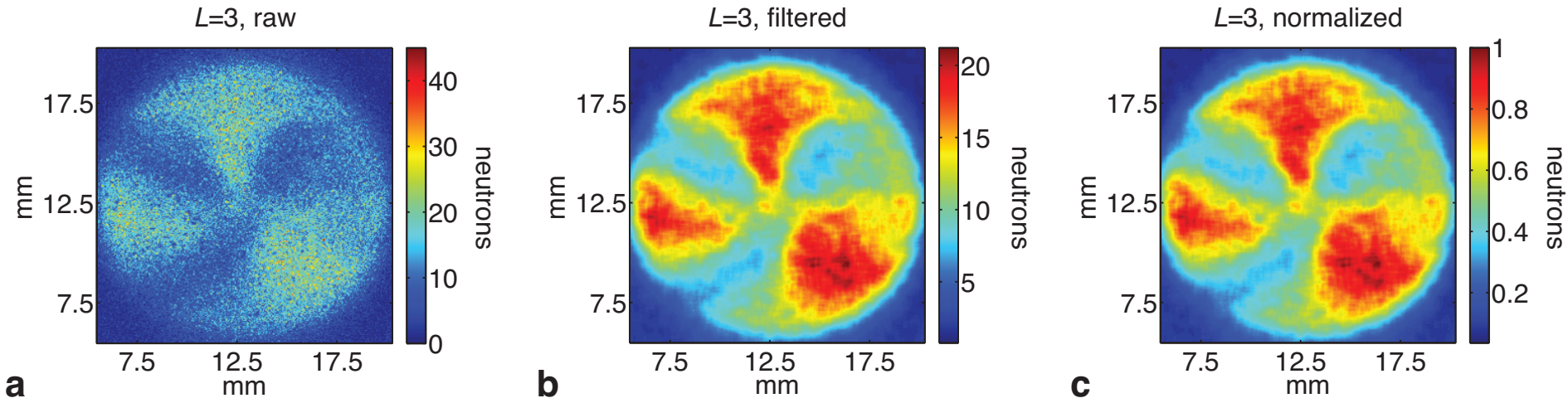
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LETTER

doi:10.1038/nature15265

Controlling neutron orbital angular momentum

Charles W. Clark[1], Roman Barankov[2], Michael G. Huber[3], Muhammad Arif[3], David G. Cory[4,5,6,7] & Dmitry A. Pushin[6,8]



C. W. Clark, et al, Nature 525(2015) 506

Vortex particles scattering with nuclei

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- Radiative capture of cold neutrons by protons and deuteron photodisintegration with twisted beams

  A. Afanasev, V. G. Serbo, M. Solyanik, J. Phys. G 72 (2018) 055102

- Schwinger scattering of twisted neutrons by nuclei

  A. Afanasev, D. V. Karlovets, V. G. Serbo, Phys. Rev. C 100 (2019) 051601

- Elastic scattering of twisted neutrons by nuclei

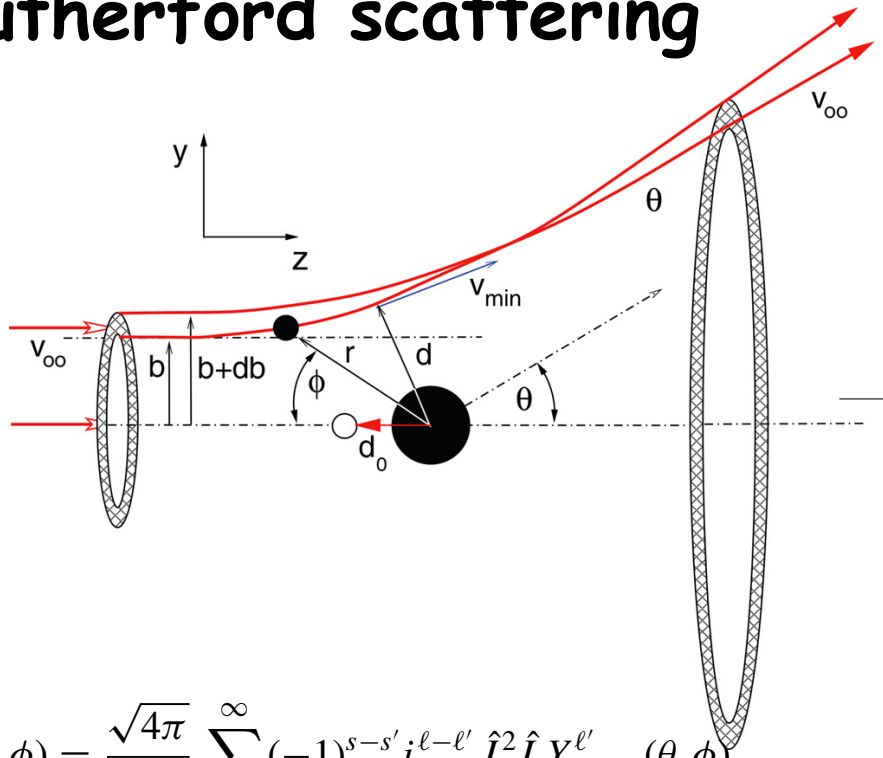
  A. Afanasev, D. V. Karlovets, V. G. Serbo, Phys. Rev. C 103 (2021) 054612

- Photoexcitation of the 229Th nuclear clock transition using twisted light

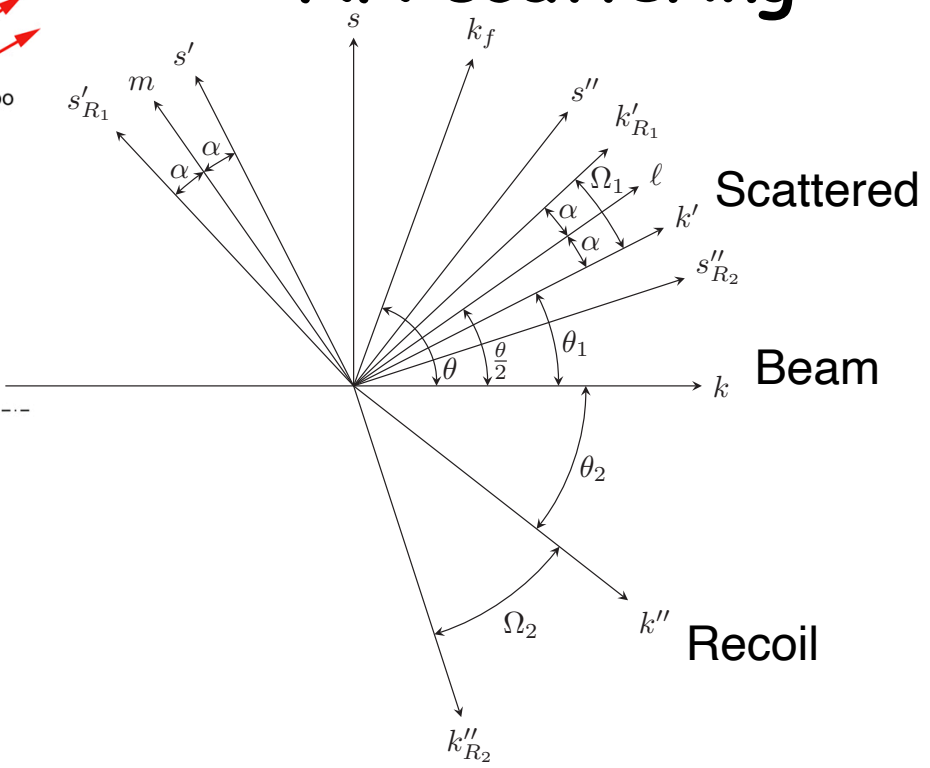
  K. Kirschbaum, T. Schumm, A. Pálffy, Phys. Rev. C 110 (2024) 064326

Nucleon-Nucleon interaction

Rutherford scattering



NN scattering



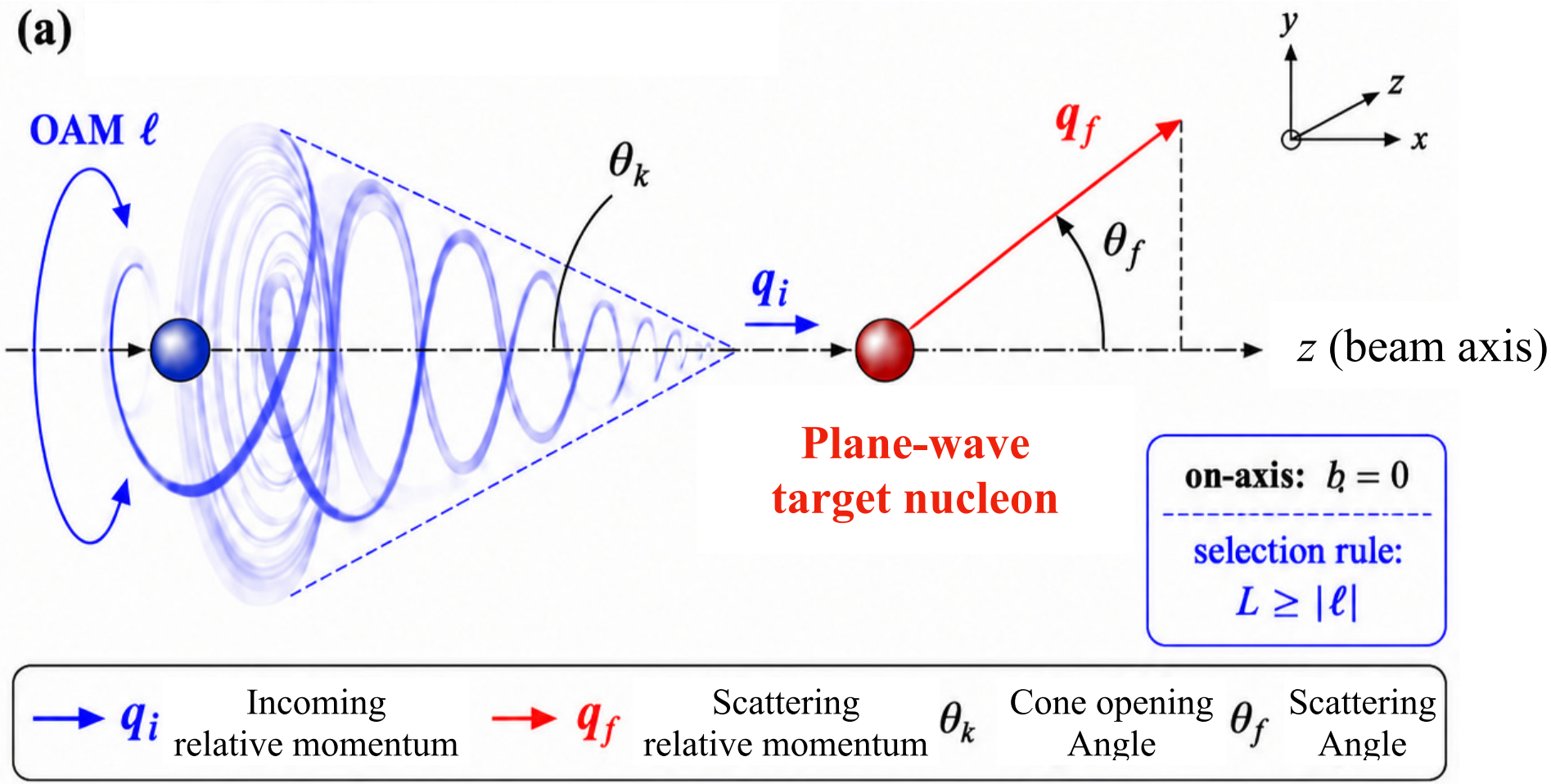
$$M^{s's}_{m'm}(\theta,\phi) = \frac{\sqrt{4\pi}}{2ip}\sum_{j,\ell,\ell'}^{\infty}(-1)^{s-s'}i^{\ell-\ell'}\hat{J}^2\hat{L}Y^{\ell'}_{m-m'}(\theta,\phi)$$

$$\times\begin{pmatrix}\ell' & s' & j\\ m-m' & m' & -m\end{pmatrix}\begin{pmatrix}\ell & s & j\\ 0 & m & -m\end{pmatrix}$$

$$\times\langle\ell's'|S^j-1|\ell s\rangle,$$

J. Bystricky, F. Lehar, and P. Winternitz, J. Phys. 39(1978)1.

On-axis scattering



J. Hu, Y. Zhang, and H. Shen, Phys. Rev. C 114(2026)034012

The plane-wave scattering amplitude in the LSJ representation is

$$\mathcal{A}^{\rm PW}_{S'\mu'_S,S\mu_S}(\hat{\mathbf{q}}_f,\hat{\mathbf{q}}_i) = \frac{4\pi}{2iq}\sum_{JLL'M} i^{L-L'}Y^*_{Lm_L}(\hat{\mathbf{q}}_i)\langle Lm_L,S\mu_S|JM\rangle \times\left[S^J_{L'S',LS}-\delta_{L'L}\delta_{S'S}\right]\langle L'm'_L,S'\mu'_S|JM\rangle Y_{L'm'_L}(\hat{\mathbf{q}}_f),$$

A Bessel-type vortex state with fixed OAM projection ℓ is written as a coherent superposition of plane waves on an azimuth angle ϕ,

$$|\kappa,q_z,\ell\rangle = \int_0^{2\pi}\frac{d\phi_i}{2\pi}e^{i\ell\phi_i}|\mathbf{q}_i(\phi_i)\rangle,$$

where

$$\mathbf{q}_i(\phi_i) = q(\sin\theta_\kappa\cos\phi_i,\sin\theta_\kappa\sin\phi_i,\cos\theta_\kappa), \qquad \theta_\kappa = \arctan\frac{\kappa}{q_z}.$$

J. Hu, Y. Zhang, and H. Shen, Phys. Rev. C 114(2026)034012

On-axis scattering

Since

$$Y^*_{Lm_L}(\theta_\kappa,\phi_i) = Y^*_{Lm_L}(\theta_\kappa,0)e^{-im_L\phi_i}$$

the azimuthal integration gives

$$\int_0^{2\pi}\frac{d\phi_i}{2\pi}e^{i\ell\phi_i}Y^*_{Lm_L}(\theta_\kappa,\phi_i) = Y^*_{L\ell}(\theta_\kappa,0)\delta_{m_L\ell}.$$

Thus the on-axis vortex state selects $m_L = \ell$.

The on-axis fixed-OAM amplitude becomes

$$\mathcal{A}^{(\ell)}_{S'\mu'_S,S\mu_S}(\theta_f,\phi_f) = \frac{4\pi}{2iq}\sum_{JLL'} i^{L-L'}Y^*_{L\ell}(\theta_\kappa,0)\langle L\ell,S\mu_S|JM\rangle \times\left[S^J_{L'S',LS}-\delta_{L'L}\delta_{S'S}\right]\langle L'm'_L,S'\mu'_S|JM\rangle Y_{L'm'_L}(\theta_f,\phi_f),$$

The condition $|m_L|\leq L$ then gives the selection rule

$$L \geq |\ell|.$$

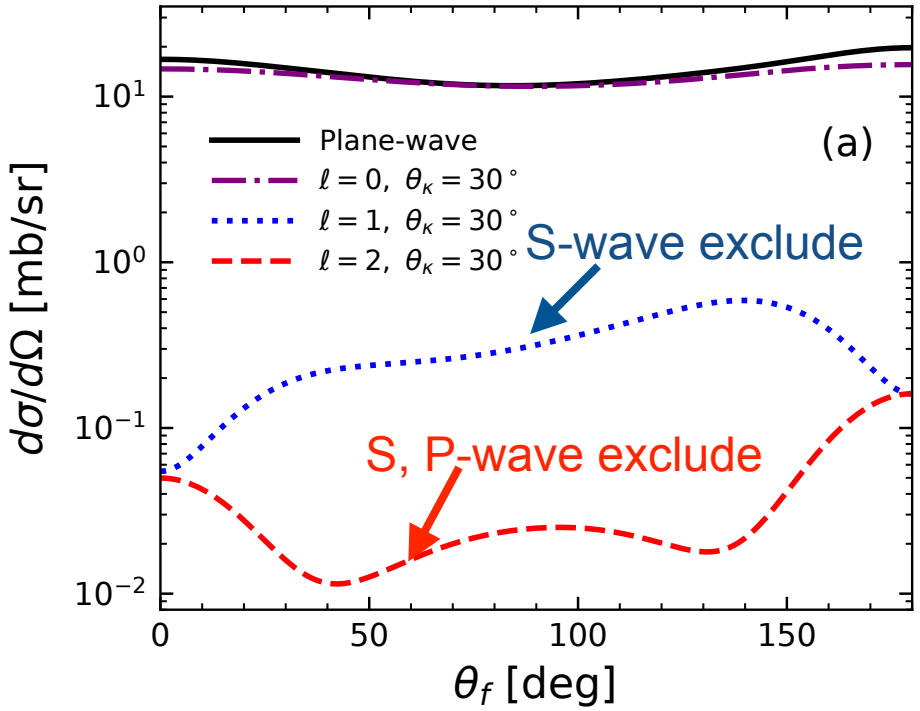
Vortex On-axis np scattering

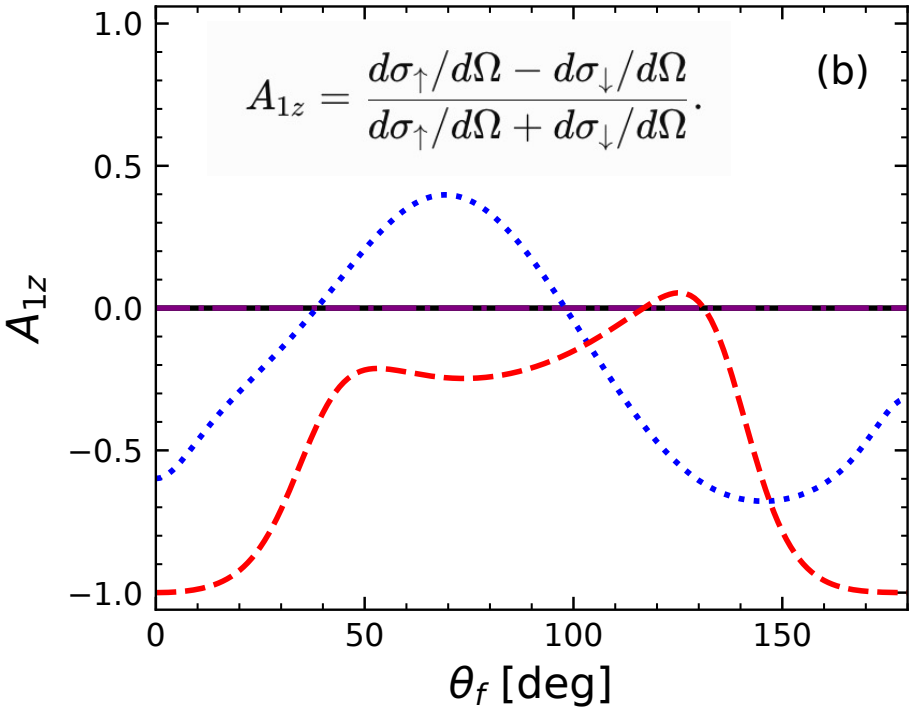
Differential cross section

$$\frac{d\sigma_\ell}{d\Omega_f} = \frac{1}{4}\,\mathrm{Tr}\left[\mathcal{M}^{(\ell)}\mathcal{M}^{(\ell)\dagger}\right] = \frac{1}{4}\sum_{S'\mu'_S,S\mu_S}\left|A^{(\ell)}_{S'\mu'_S,S\mu_S}\right|^2$$

Longitudinal beam analyzing power

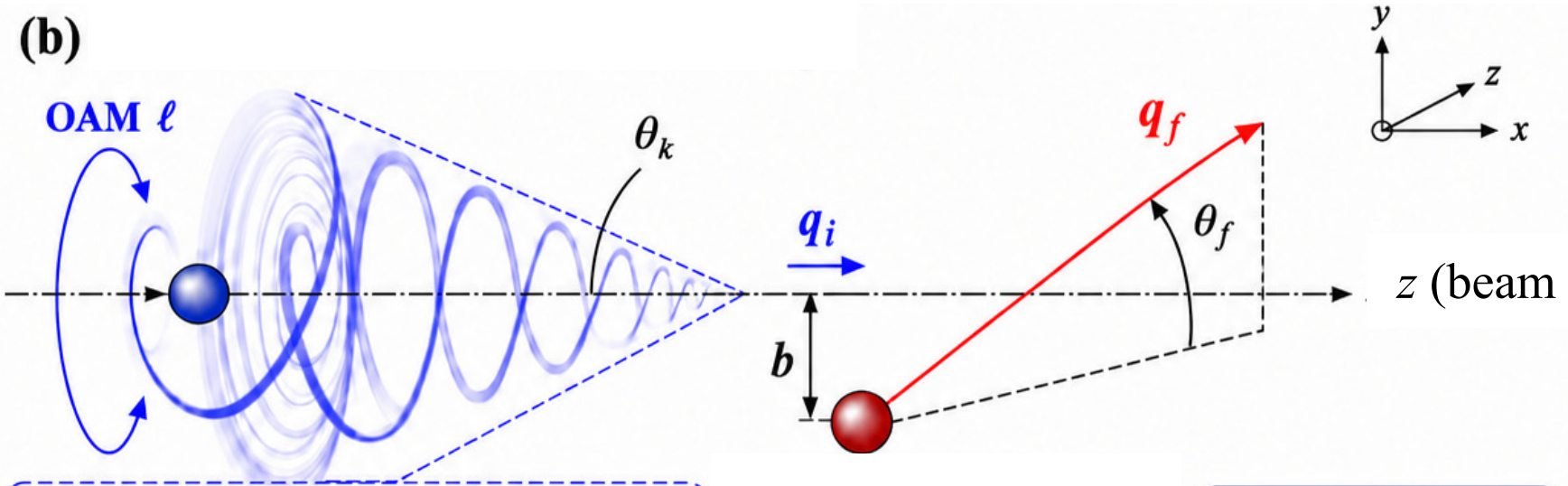
$$A_{1z} = \frac{\mathrm{Tr}[\mathcal{M}^{(\ell)}(\sigma_z \otimes I)\mathcal{M}^{(\ell)\dagger}]}{\mathrm{Tr}[\mathcal{M}^{(\ell)}\mathcal{M}^{(\ell)\dagger}]}.$$





J. Hu, Y. Zhang, and H. Shen, Phys. Rev. C 114(2026)034012

Off-axis scattering



b	Impact parameter	ℓ	OAM on z axis	L	Total OAM

Off-axis scattering

For a target displaced from the vortex axis by

$$\mathbf{b} = b(\cos\phi_b, \sin\phi_b, 0)$$

each plane-wave component acquires the phase

$$e^{-i\mathbf{q}_{i\perp}\cdot\mathbf{b}} = e^{-i\kappa b\cos(\phi_i-\phi_b)}$$

Using

$$e^{-i\kappa b\cos(\phi_i-\phi_b)} = \sum_{n=-\infty}^{\infty}(-i)^n J_n(\kappa b)e^{in(\phi_i-\phi_b)},$$

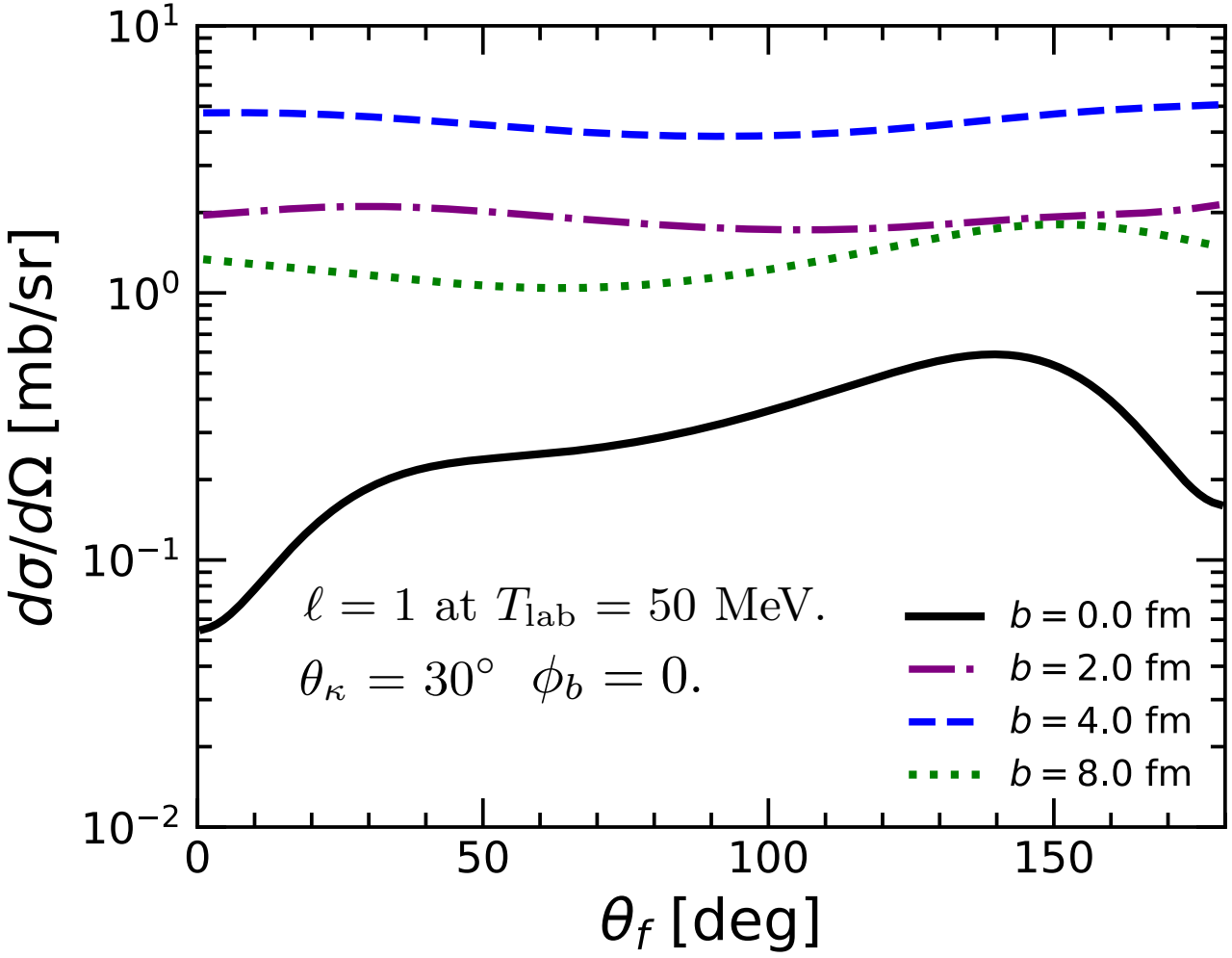
the incoming coefficient becomes

$$C_{Lm}^{(\ell)}(\theta_\kappa, \kappa b, \phi_b) = Y_{Lm}^*(\theta_\kappa, 0)(-i)^{m-\ell}J_{m-\ell}(\kappa b)e^{-i(m-\ell)\phi_b}.$$

The off-axis amplitude is

$$\mathcal{A}^{(\ell)}_{S'\mu'_S,S\mu_S}(\theta_f,\phi_f;\mathbf{b}) = \frac{4\pi}{2iq}\sum_{JLL'm} i^{L-L'}C_{Lm}^{(\ell)}(\theta_\kappa,\kappa b,\phi_b)\langle Lm, S\mu_S|JM\rangle \times\left[S^J_{L'S',LS}-\delta_{L'L}\delta_{S'S}\right]\langle L'm'_L, S'\mu'_S|JM\rangle Y_{L'm'_L}(\theta_f,\phi_f),$$

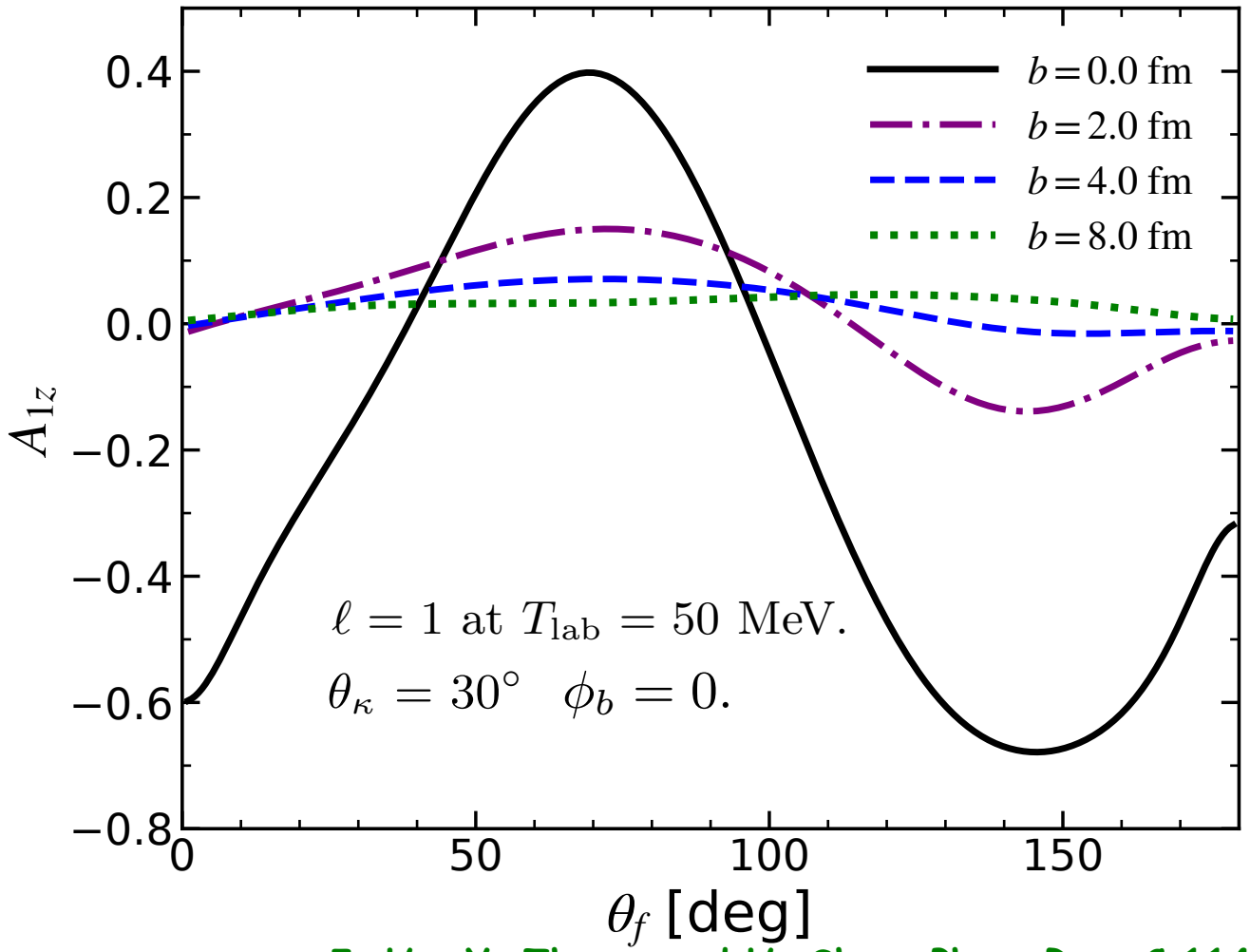
Vortex off-axis scattering



J. Hu, Y. Zhang, and H. Shen, Phys. Rev. C 114(2026)034012

Vortex off-axis scattering

Longitudinal beam analyzing power



J. Hu, Y. Zhang, and H. Shen, Phys. Rev. C 114(2026)034012

The summary and outlook

The nucleon-nucleon scattering with a incident particle was investigated.

The vortex external state imposes an additional angular-momentum, which can study the partial wave structure of NN interaction.

Off-axis scattering introduces Bessel-function mixing.

Vortex nucleons provide a way to control the entrance partial-wave content of NN scattering without modifying the underlying nuclear interaction.

Vortex photon induced Photodisintegration

