

基研研究会「微視的核反応理論による物理」(Aug. 1-3, 2011 at YITP)

微視的模型を用いた原子核散乱反応 におけるエネルギー依存性

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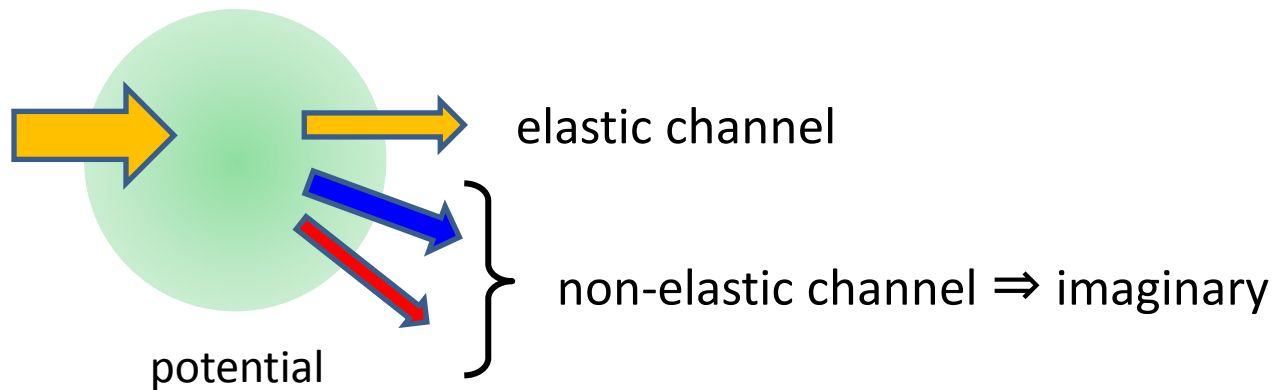
Y. Yamamoto (RIKEN)

Introduction

- **Optical model potential (OMP)**

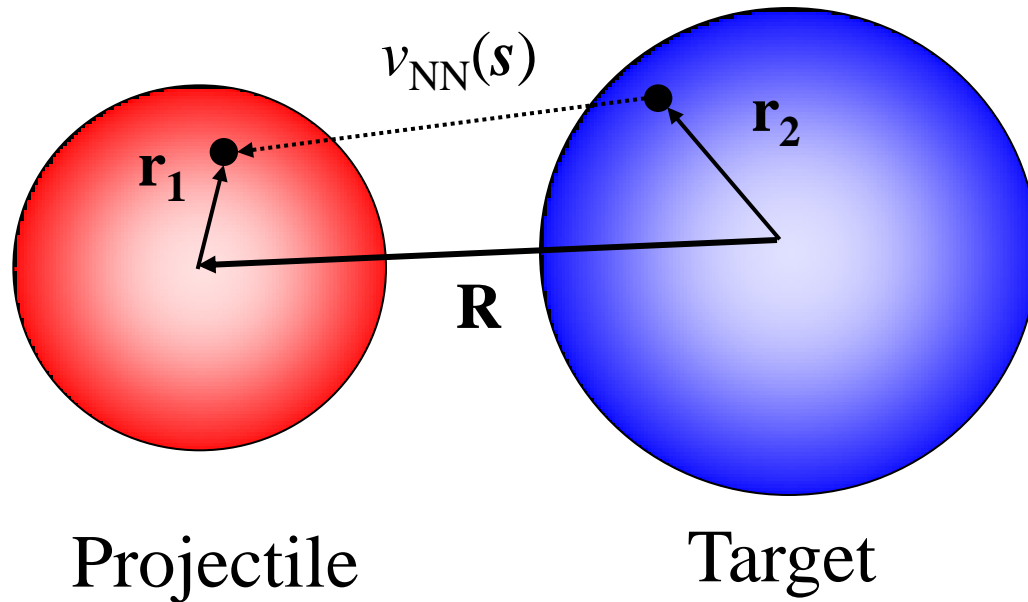
- is complex potential

- has the imaginary part that represents the loss of flux
in elastic scattering



$$U_{opt}(r) = V(r) + iW(r)$$

Double-Folding Model (DFM)



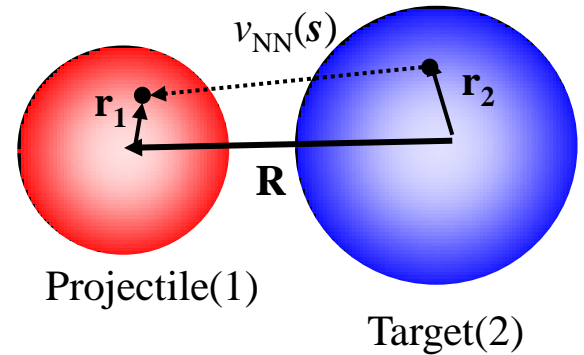
$$U_{opt}(\mathbf{R}) = \int \rho_1(\mathbf{r}_1) \rho_2(\mathbf{r}_2) v_{NN}(\mathbf{s}; \rho, E) d\mathbf{r}_1 d\mathbf{r}_2$$

nucleon density

effective NN interaction

Double-Folding Model (DFM)

with complex G-matrix interaction



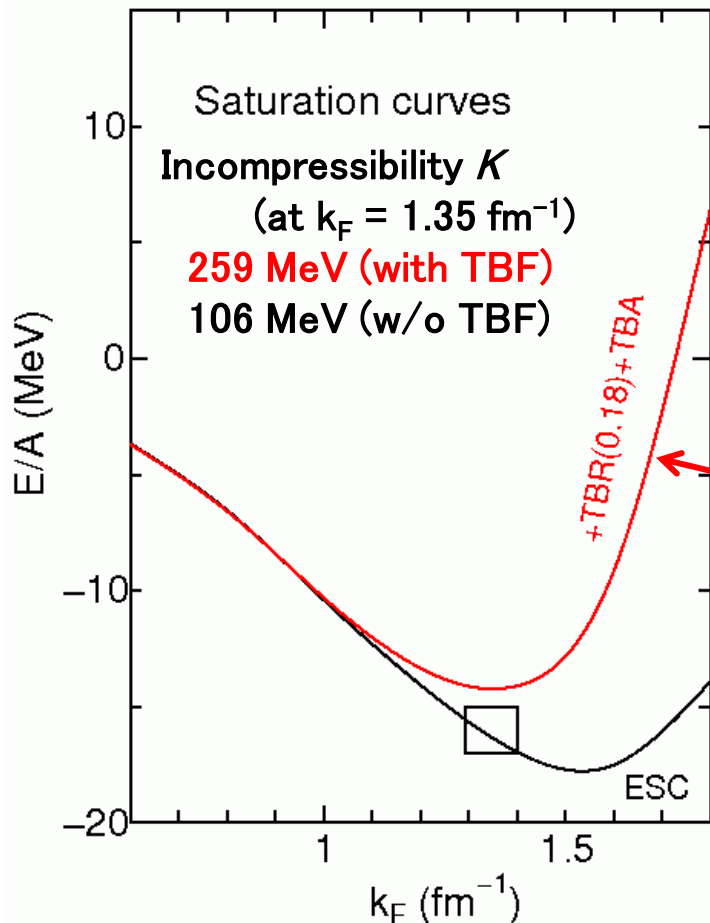
Folding model potential

$$U(\mathbf{R}) = V_{DFM}(\mathbf{R}) + iW_{DFM}(\mathbf{R})$$

$$= \int \rho_1(\mathbf{r}_1) \rho_2(\mathbf{r}_2) \underline{v_{NN}(\mathbf{s}; \rho, E)} d\mathbf{r}_1 d\mathbf{r}_2$$

Interaction

CEG07 (complex G-matrix interaction)



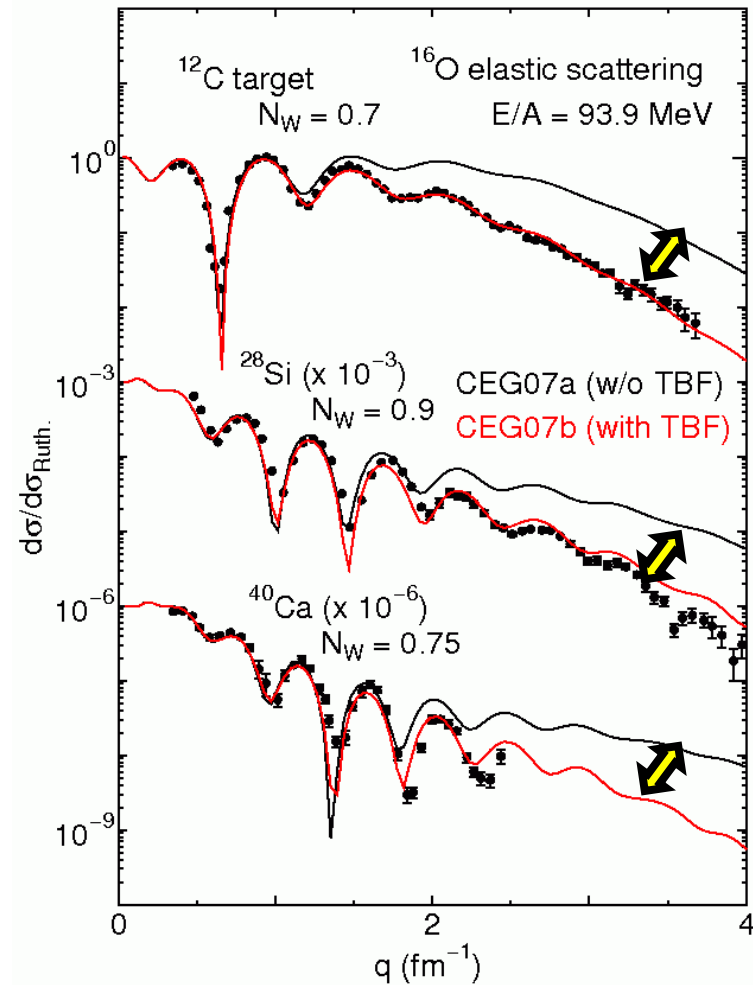
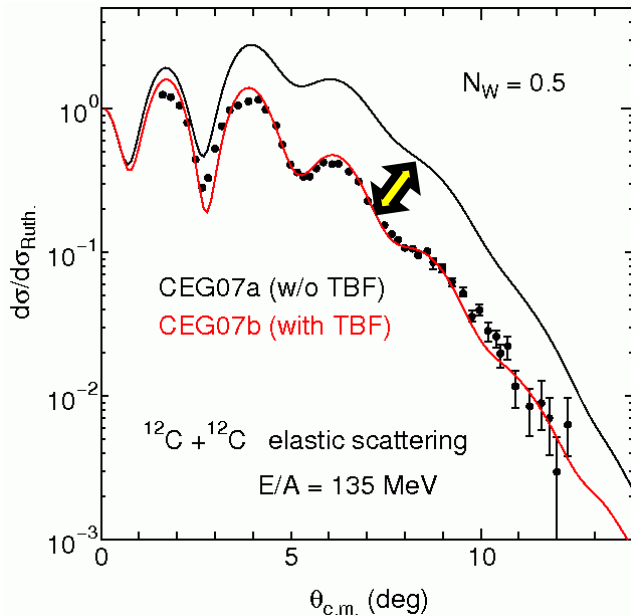
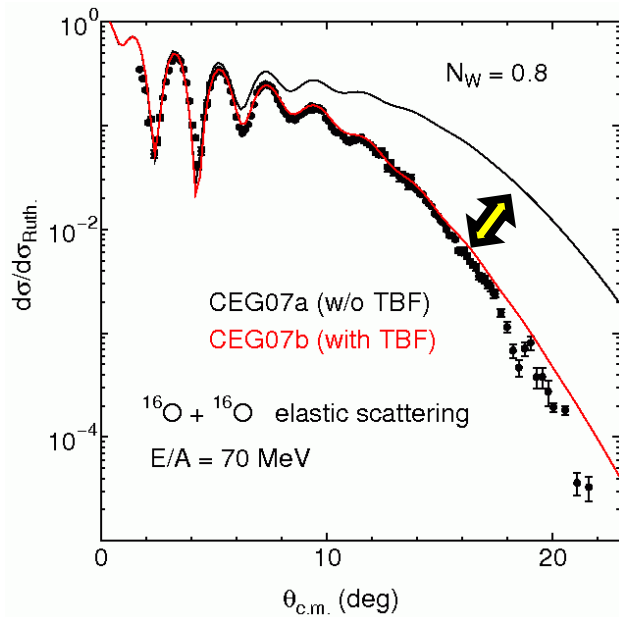
CEG07b (with TBF)

CEG07a (w/o TBF)

T. Furumoto, Y. Sakuragi and Y. Yamamoto,
(*Phys. Rev. C.79 (2009) 011601(R), ibid. 80 (2009) 044614*)

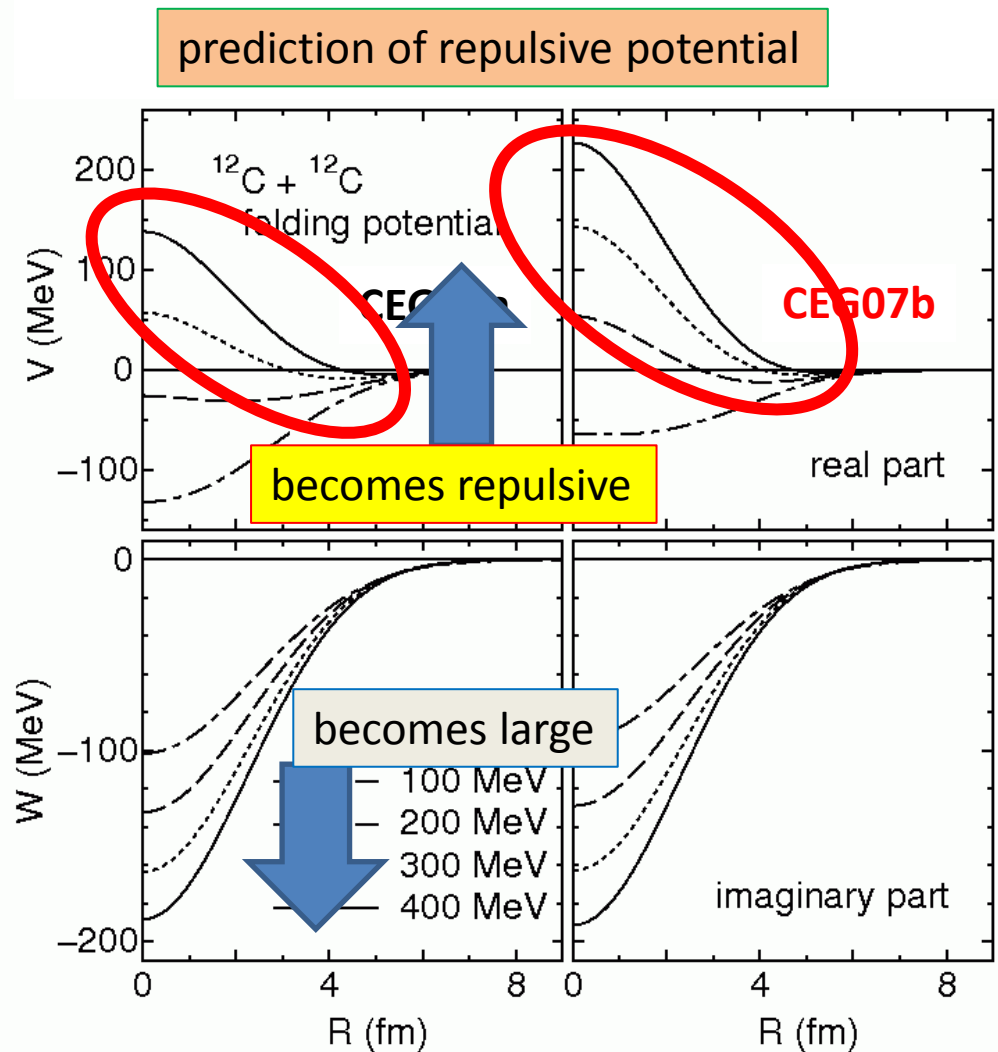
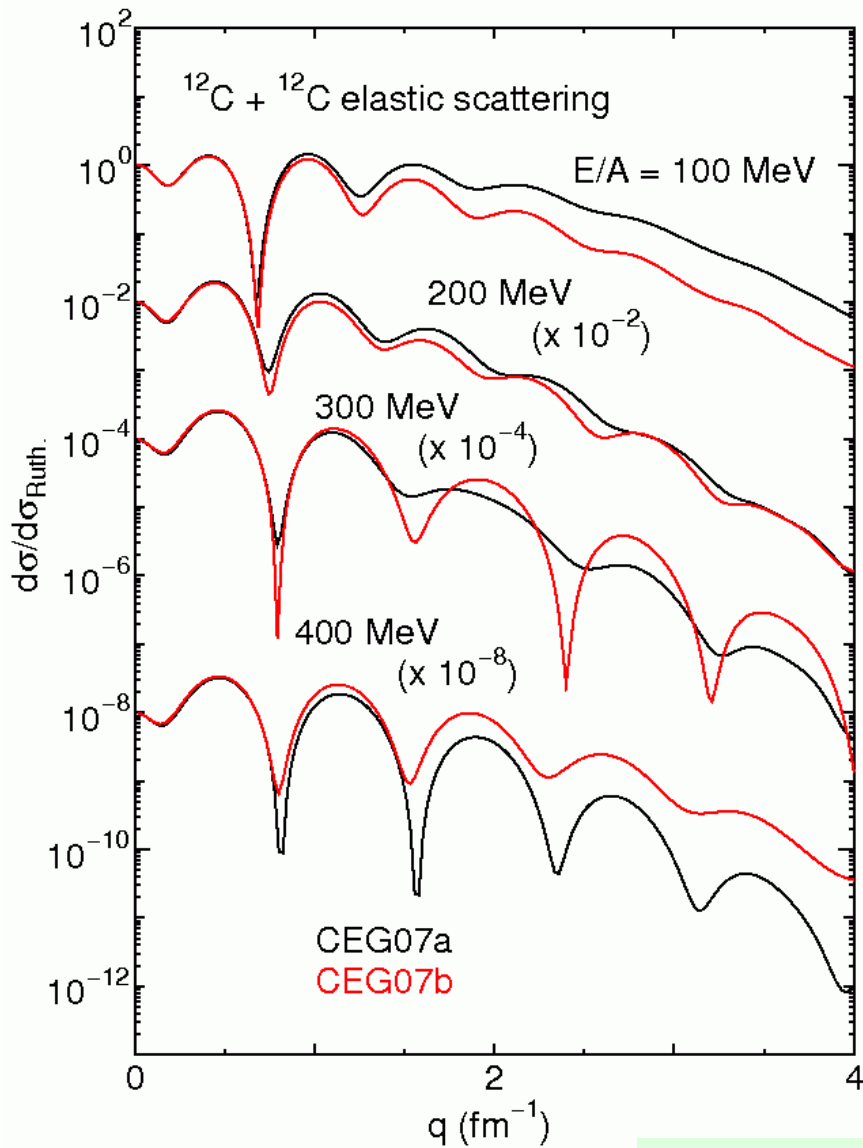
Heavy-ion elastic scattering

Important effect of three-body force



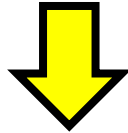
T. Furumoto, Y. Sakuragi and Y. Yamamoto,
(Phys. Rev. C.79 (2009) 011601(R)), ibid. 80 (2009) 044614)

$^{12}\text{C} + ^{12}\text{C}$ elastic scattering at various energies



About repulsive potential

In general, nuclear interaction is attractive.



By several reasons, nuclear interaction becomes repulsive

- medium effect (Pauli principle, three-body force)
- **energy dependence**



The repulsive potential is obtained in the high-energy region.

Examples

- Dirac phenomenology (p-A, d-A)
- microscopic approach (p-A)
- phenomenological optical model analysis (α -A)

About repulsive part

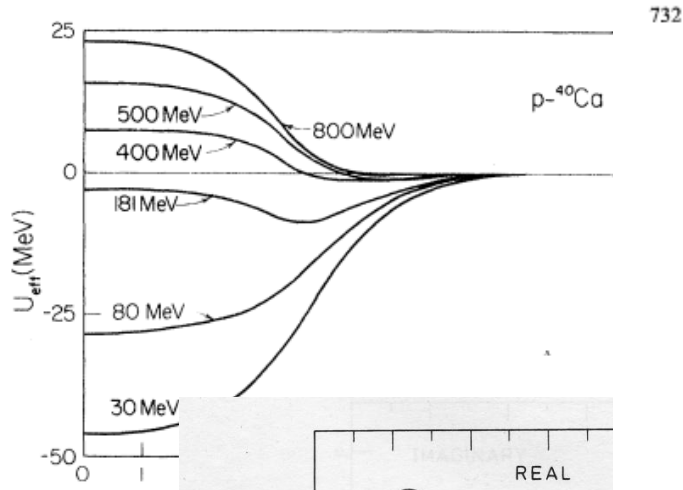


FIG. 2. The central potential based analysis (Refs. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134, 135, 136, 137, 138, 139, 140, 141, 142, 143, 144, 145, 146, 147, 148, 149, 150, 151, 152, 153, 154, 155, 156, 157, 158, 159, 160, 161, 162, 163, 164, 165, 166, 167, 168, 169, 170, 171, 172, 173, 174, 175, 176, 177, 178, 179, 180, 181, 182, 183, 184, 185, 186, 187, 188, 189, 190, 191, 192, 193, 194, 195, 196, 197, 198, 199, 200, 201, 202, 203, 204, 205, 206, 207, 208, 209, 210, 211, 212, 213, 214, 215, 216, 217, 218, 219, 220, 221, 222, 223, 224, 225, 226, 227, 228, 229, 230, 231, 232, 233, 234, 235, 236, 237, 238, 239, 240, 241, 242, 243, 244, 245, 246, 247, 248, 249, 250, 251, 252, 253, 254, 255, 256, 257, 258, 259, 260, 261, 262, 263, 264, 265, 266, 267, 268, 269, 270, 271, 272, 273, 274, 275, 276, 277, 278, 279, 280, 281, 282, 283, 284, 285, 286, 287, 288, 289, 290, 291, 292, 293, 294, 295, 296, 297, 298, 299, 300, 301, 302, 303, 304, 305, 306, 307, 308, 309, 310, 311, 312, 313, 314, 315, 316, 317, 318, 319, 320, 321, 322, 323, 324, 325, 326, 327, 328, 329, 330, 331, 332, 333, 334, 335, 336, 337, 338, 339, 340, 341, 342, 343, 344, 345, 346, 347, 348, 349, 350, 351, 352, 353, 354, 355, 356, 357, 358, 359, 360, 361, 362, 363, 364, 365, 366, 367, 368, 369, 370, 371, 372, 373, 374, 375, 376, 377, 378, 379, 380, 381, 382, 383, 384, 385, 386, 387, 388, 389, 390, 391, 392, 393, 394, 395, 396, 397, 398, 399, 400, 401, 402, 403, 404, 405, 406, 407, 408, 409, 410, 411, 412, 413, 414, 415, 416, 417, 418, 419, 420, 421, 422, 423, 424, 425, 426, 427, 428, 429, 430, 431, 432, 433, 434, 435, 436, 437, 438, 439, 440, 441, 442, 443, 444, 445, 446, 447, 448, 449, 450, 451, 452, 453, 454, 455, 456, 457, 458, 459, 460, 461, 462, 463, 464, 465, 466, 467, 468, 469, 470, 471, 472, 473, 474, 475, 476, 477, 478, 479, 480, 481, 482, 483, 484, 485, 486, 487, 488, 489, 490, 491, 492, 493, 494, 495, 496, 497, 498, 499, 500, 501, 502, 503, 504, 505, 506, 507, 508, 509, 510, 511, 512, 513, 514, 515, 516, 517, 518, 519, 520, 521, 522, 523, 524, 525, 526, 527, 528, 529, 530, 531, 532, 533, 534, 535, 536, 537, 538, 539, 540, 541, 542, 543, 544, 545, 546, 547, 548, 549, 550, 551, 552, 553, 554, 555, 556, 557, 558, 559, 560, 561, 562, 563, 564, 565, 566, 567, 568, 569, 570, 571, 572, 573, 574, 575, 576, 577, 578, 579, 580, 581, 582, 583, 584, 585, 586, 587, 588, 589, 590, 591, 592, 593, 594, 595, 596, 597, 598, 599, 600, 601, 602, 603, 604, 605, 606, 607, 608, 609, 610, 611, 612, 613, 614, 615, 616, 617, 618, 619, 620, 621, 622, 623, 624, 625, 626, 627, 628, 629, 630, 631, 632, 633, 634, 635, 636, 637, 638, 639, 640, 641, 642, 643, 644, 645, 646, 647, 648, 649, 650, 651, 652, 653, 654, 655, 656, 657, 658, 659, 660, 661, 662, 663, 664, 665, 666, 667, 668, 669, 670, 671, 672, 673, 674, 675, 676, 677, 678, 679, 680, 681, 682, 683, 684, 685, 686, 687, 688, 689, 690, 691, 692, 693, 694, 695, 696, 697, 698, 699, 700, 701, 702, 703, 704, 705, 706, 707, 708, 709, 710, 711, 712, 713, 714, 715, 716, 717, 718, 719, 720, 721, 722, 723, 724, 725, 726, 727, 728, 729, 730, 731, 732, 733, 734, 735, 736, 737, 738, 739, 740, 741, 742, 743, 744, 745, 746, 747, 748, 749, 750, 751, 752, 753, 754, 755, 756, 757, 758, 759, 760, 761, 762, 763, 764, 765, 766, 767, 768, 769, 770, 771, 772, 773, 774, 775, 776, 777, 778, 779, 780, 781, 782, 783, 784, 785, 786, 787, 788, 789, 790, 791, 792, 793, 794, 795, 796, 797, 798, 799, 800, 801, 802, 803, 804, 805, 806, 807, 808, 809, 810, 811, 812, 813, 814, 815, 816, 817, 818, 819, 820, 821, 822, 823, 824, 825, 826, 827, 828, 829, 830, 831, 832, 833, 834, 835, 836, 837, 838, 839, 840, 841, 842, 843, 844, 845, 846, 847, 848, 849, 850, 851, 852, 853, 854, 855, 856, 857, 858, 859, 860, 861, 862, 863, 864, 865, 866, 867, 868, 869, 870, 871, 872, 873, 874, 875, 876, 877, 878, 879, 880, 881, 882, 883, 884, 885, 886, 887, 888, 889, 890, 891, 892, 893, 894, 895, 896, 897, 898, 899, 900, 901, 902, 903, 904, 905, 906, 907, 908, 909, 910, 911, 912, 913, 914, 915, 916, 917, 918, 919, 920, 921, 922, 923, 924, 925, 926, 927, 928, 929, 930, 931, 932, 933, 934, 935, 936, 937, 938, 939, 940, 941, 942, 943, 944, 945, 946, 947, 948, 949, 950, 951, 952, 953, 954, 955, 956, 957, 958, 959, 960, 961, 962, 963, 964, 965, 966, 967, 968, 969, 970, 971, 972, 973, 974, 975, 976, 977, 978, 979, 980, 981, 982, 983, 984, 985, 986, 987, 988, 989, 990, 991, 992, 993, 994, 995, 996, 997, 998, 999, 1000).

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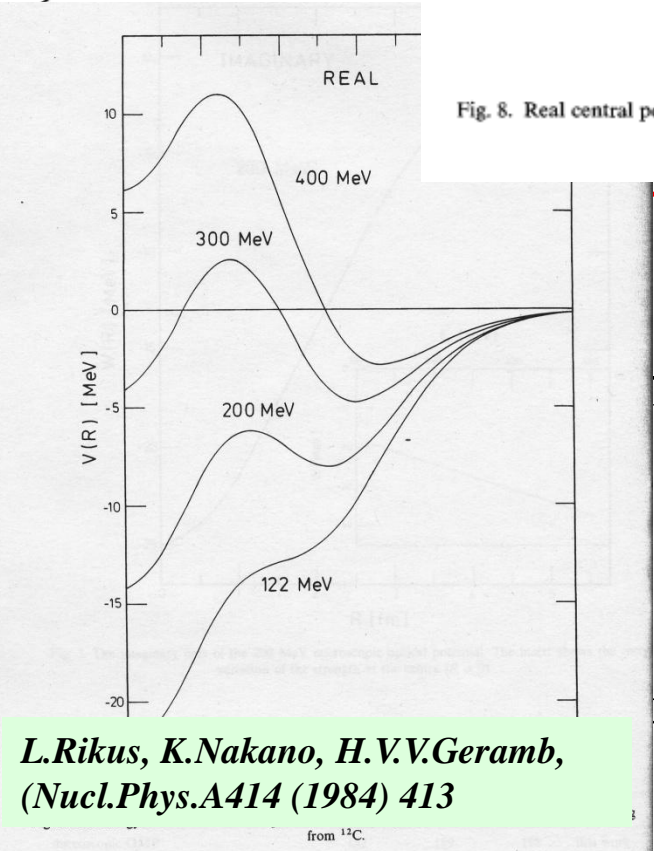
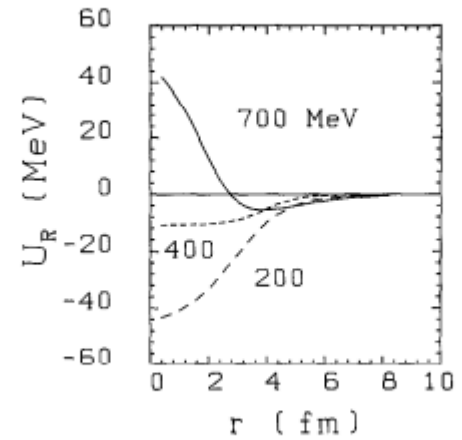


Fig. 8. Real central potential for $d+^{16}O$ (solid line), calculated from ^{12}C .

L.Rikus, K.Nakano, H.V.V.Geramb, (Nucl.Phys.A414 (1984) 413)

Nguyen Van Sen et al. / $^{16}O(d, d)$



N.V.Sen, (Nucl.Phys.A464 (1987) 717)

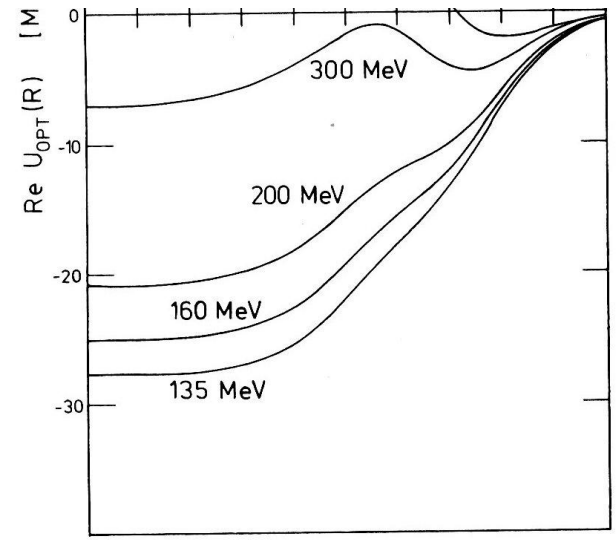
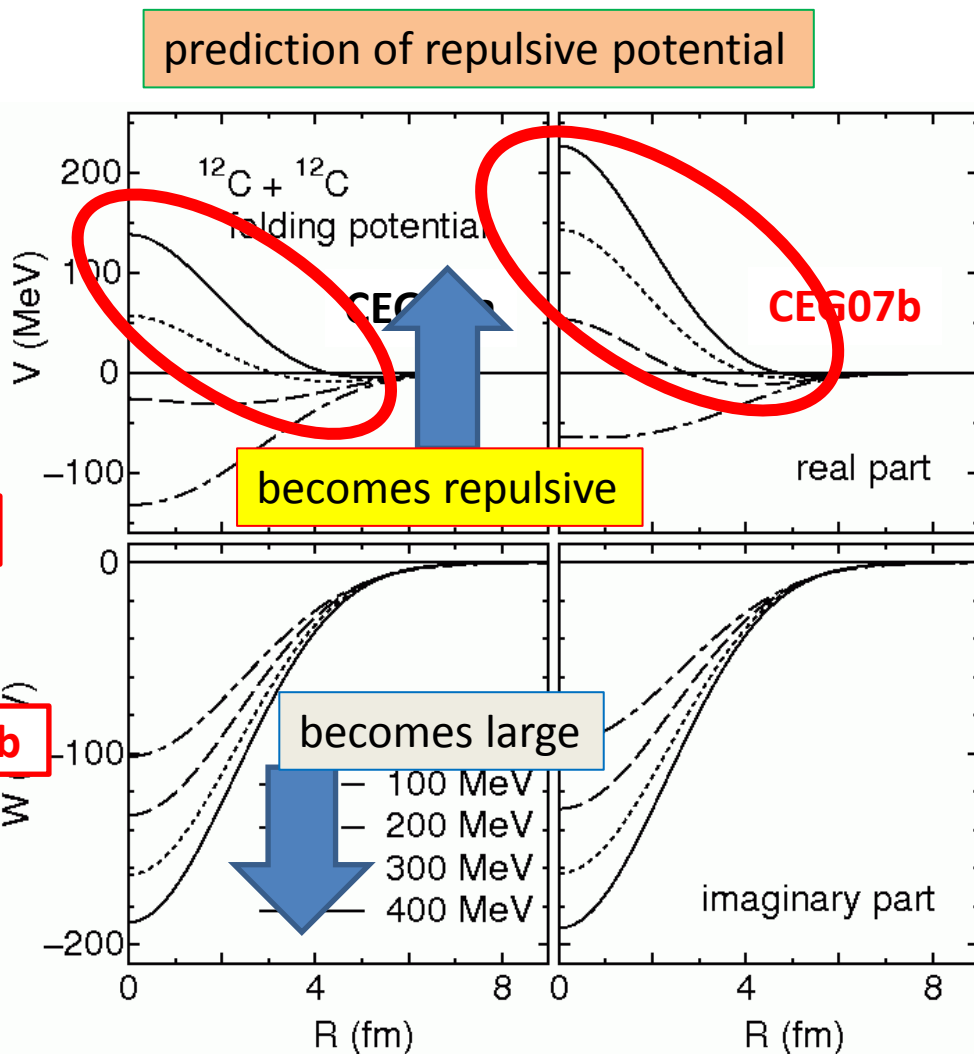
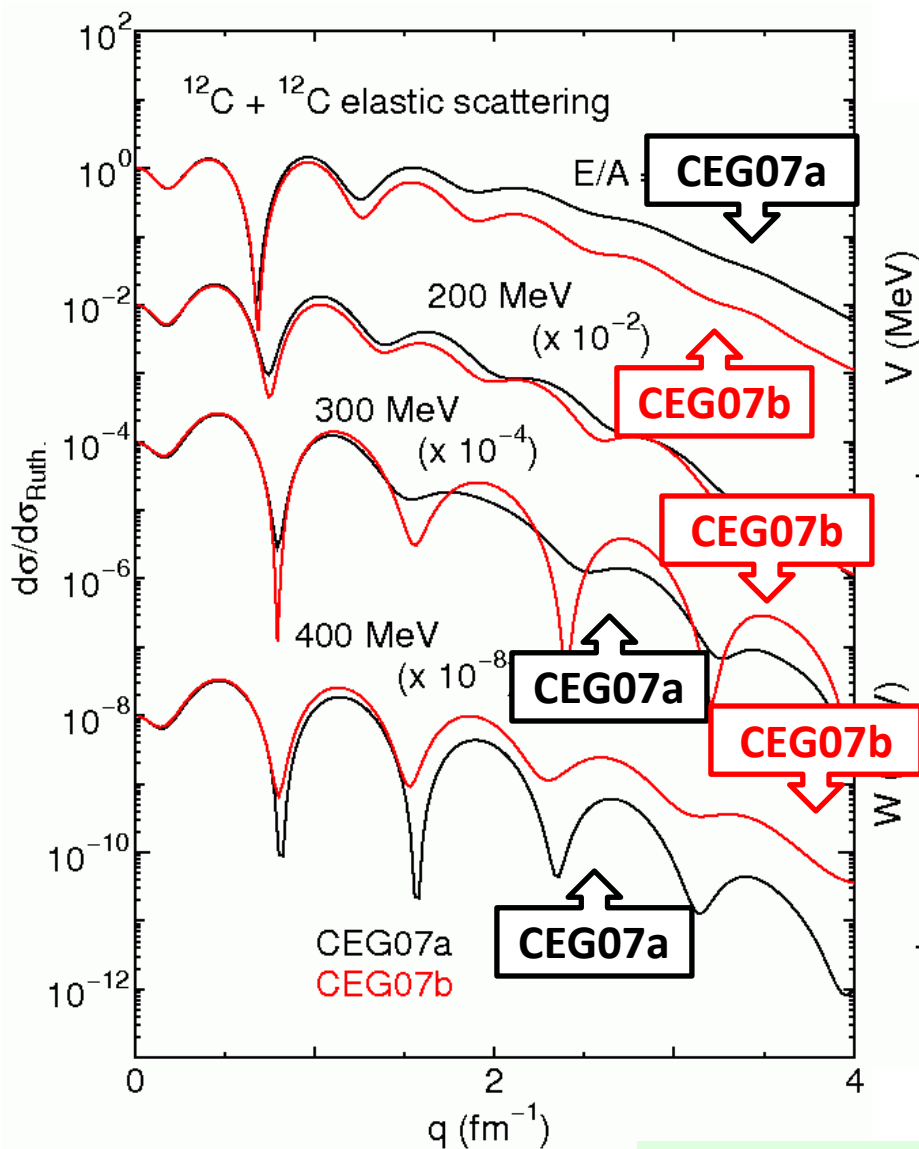
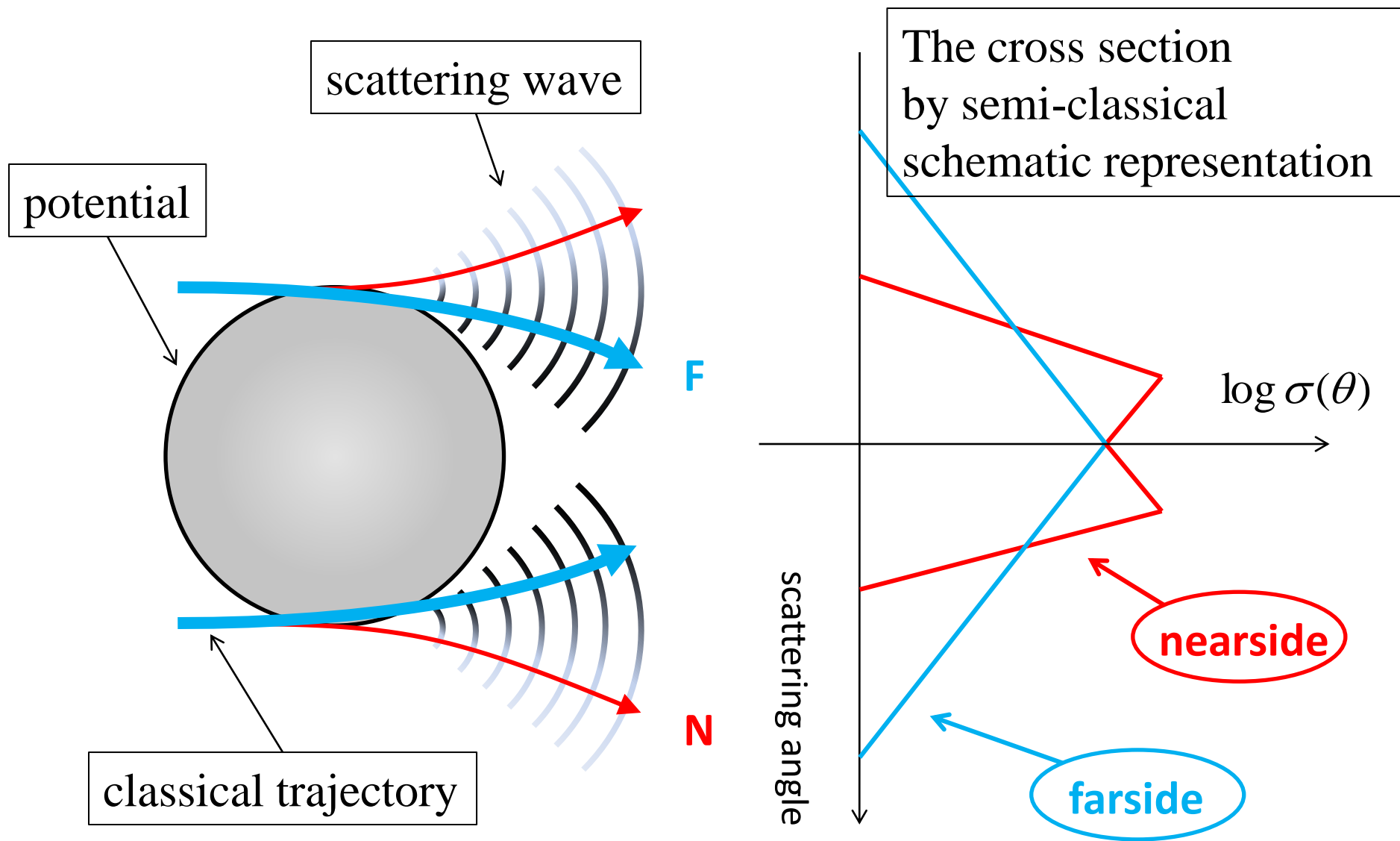


Fig. 208 Pt L.Rikus, H.V.V.Geramb, (Nucl.Phys.A426 (1984) 496)

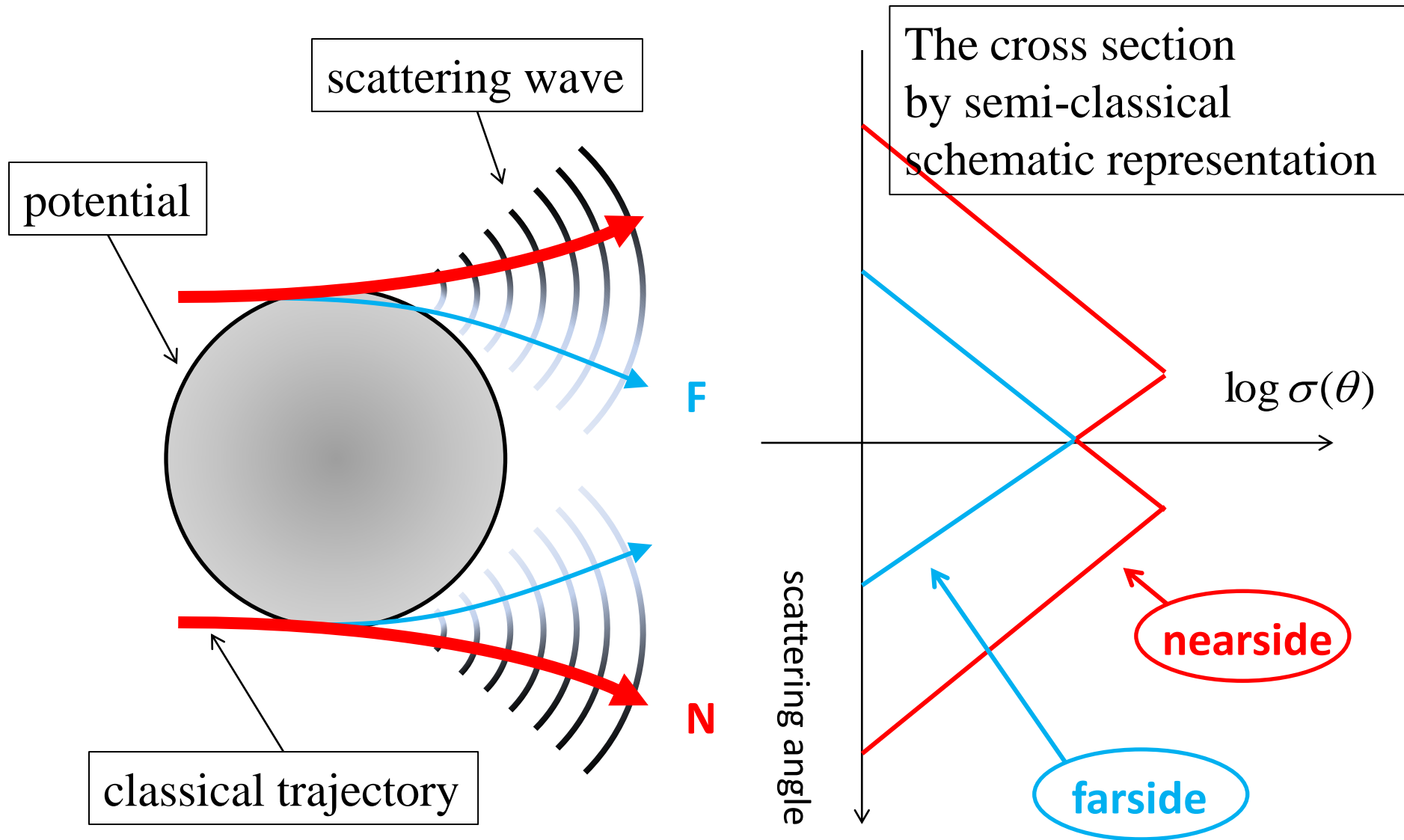
$^{12}\text{C} + ^{12}\text{C}$ elastic scattering at various energies



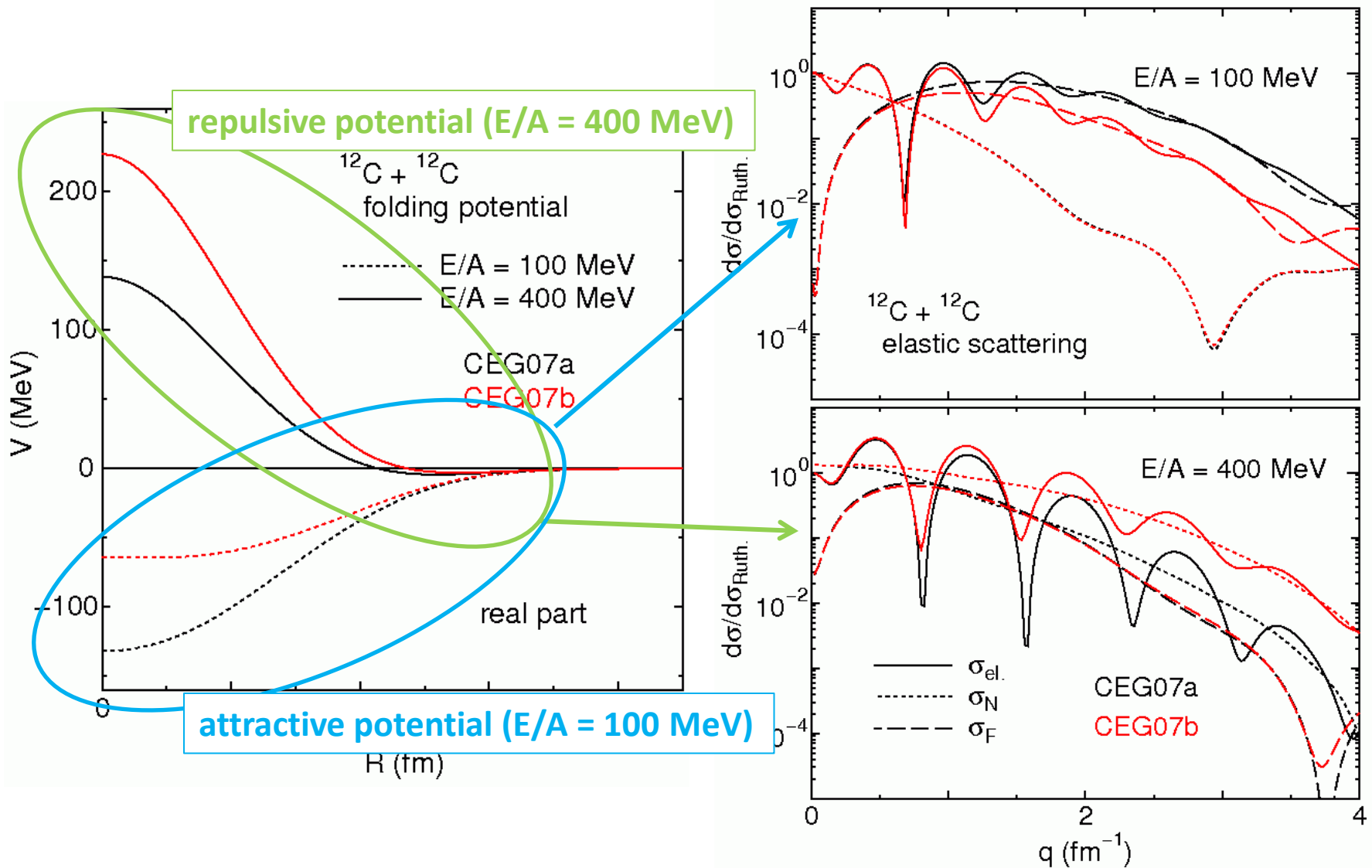
(a) Attractive potential ($V < 0$)



(b) Repulsive potential ($V > 0$)

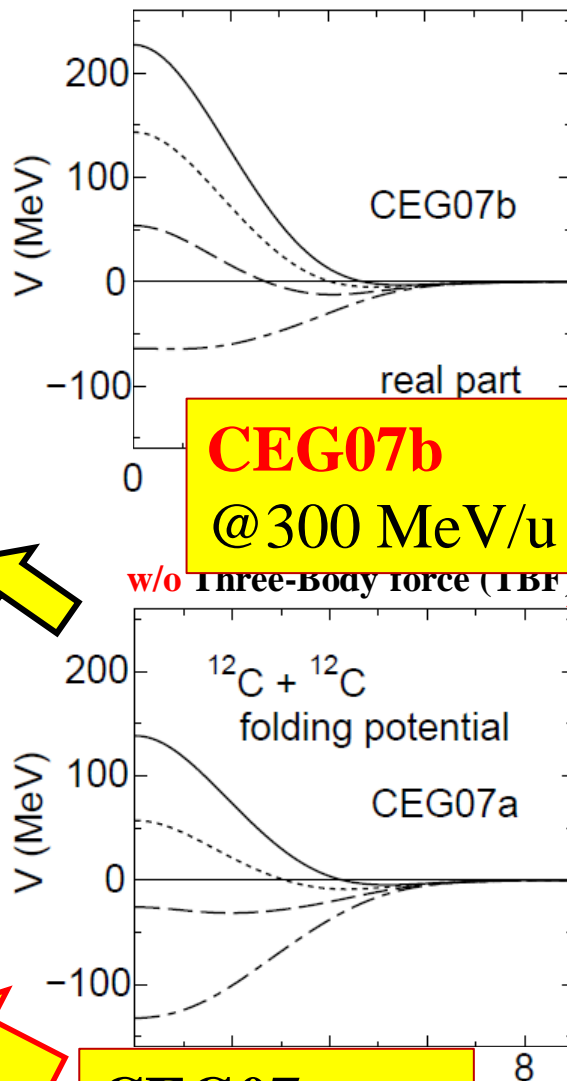
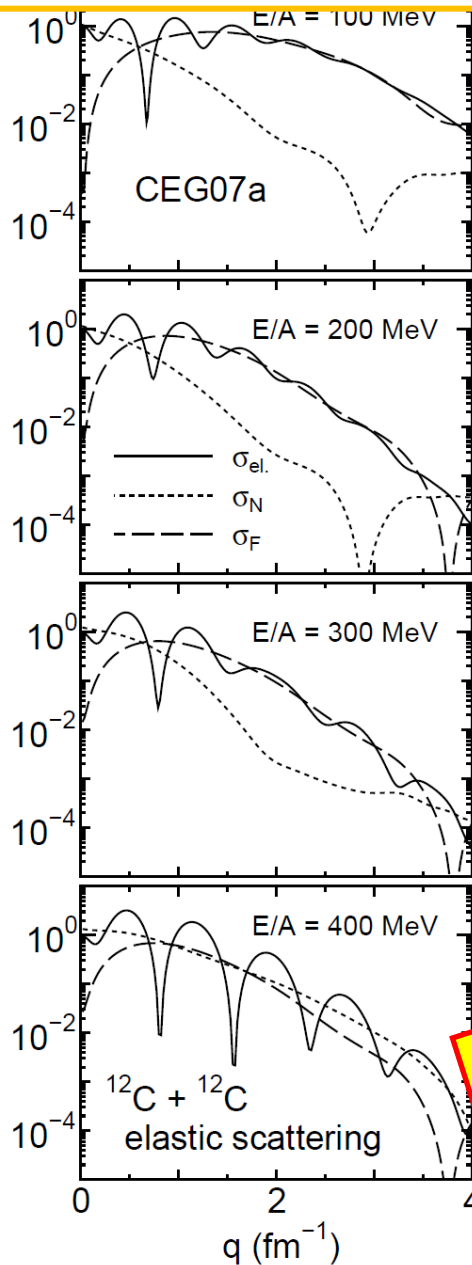


Nearside and farside (N/F) decomposition



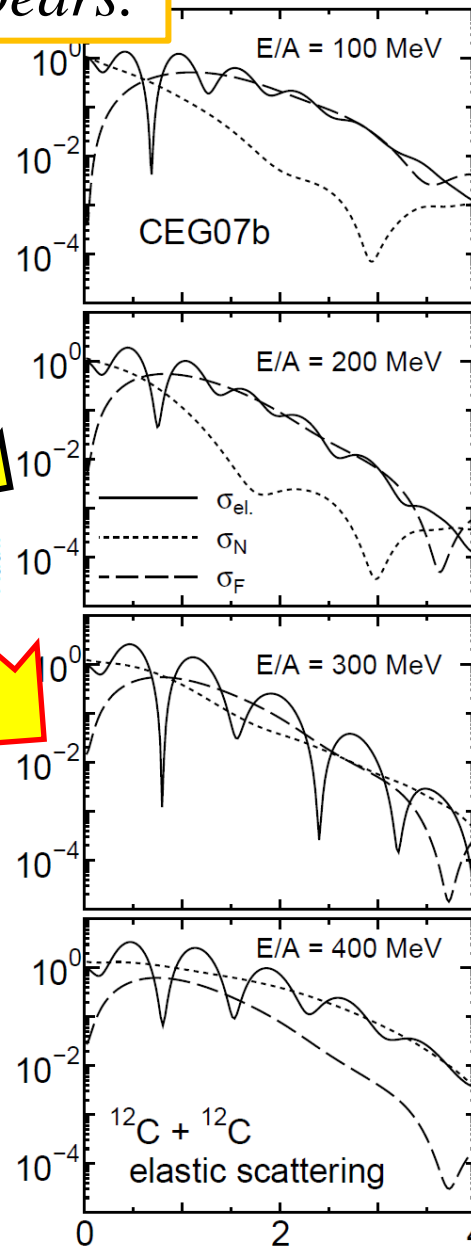
The strong interference of N/F components appears.

Free-Body force (TBF)



CEG07b
@300 MeV/u

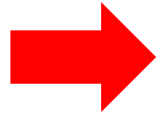
CEG07a
@400 MeV/u





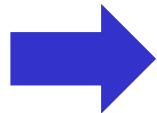
Next step

- **Inelastic cross section**



Today

- **Dynamical coupling effect to elastic cross section**



JPS meeting (19pSF-4)

Microscopic Coupled Channel (MCC) with CEG07

Coupled Channel equation

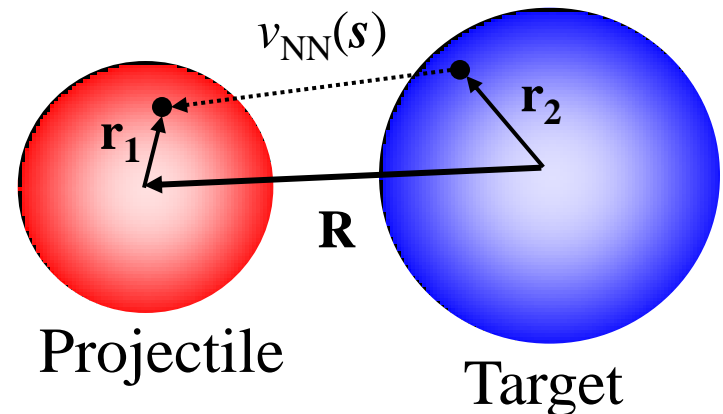
$$\left[T_R + V_{\alpha\alpha}(R) - E_\alpha \right] \chi_\alpha(R) = - \sum_{\beta \neq \alpha}^N V_{\alpha\beta}(R) \chi_\beta(R)$$

The diagonal and coupling potentials are derived from microscopic view point.

$$V_{\alpha\beta}(R) = \int \underbrace{\rho_{\alpha\beta}^{(P)}(r_1)}_{\text{transition density}} \underbrace{\rho_{\alpha\beta}^{(T)}(r_2)}_{\text{CEG07}} v_{NN}(\mathbf{s}; \rho, E) dr_1 dr_2$$

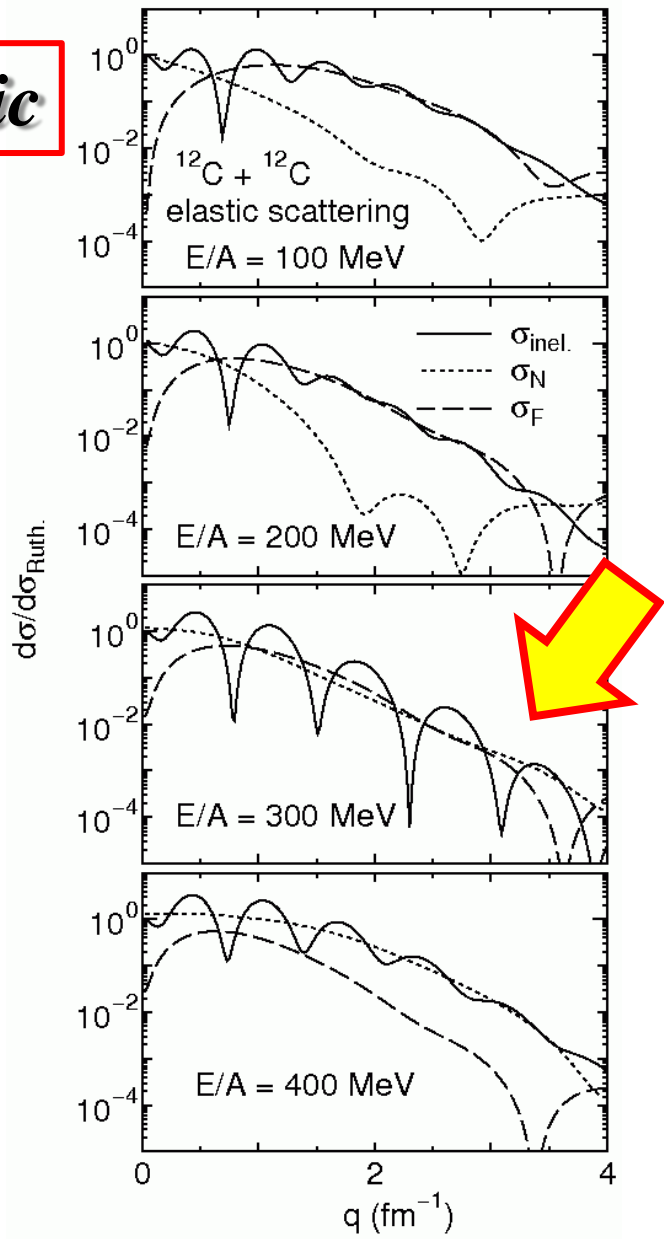
Transition density

$$\rho_{ik}(\vec{r}) = \langle \varphi_i(\xi) | \sum_i \delta(\vec{r}_i - \vec{r}) | \varphi_k(\xi) \rangle$$

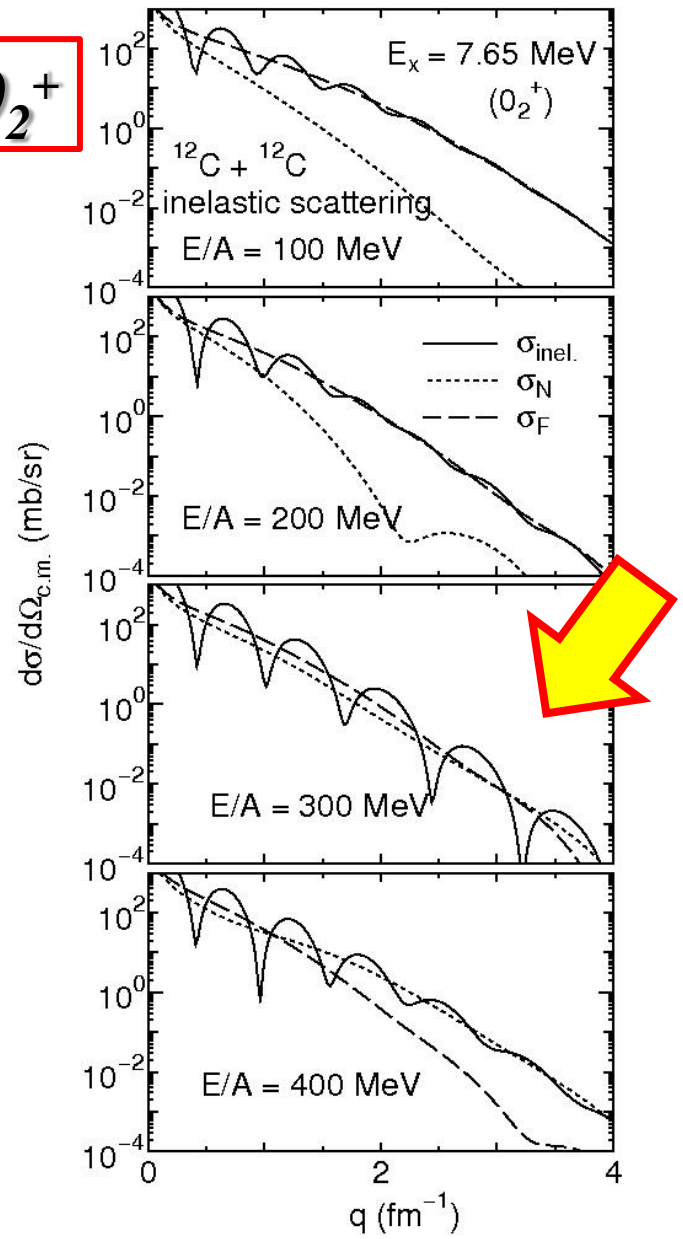


$^{12}\text{C} + ^{12}\text{C}$ elastic and inelastic scatterings at various energies

Elastic

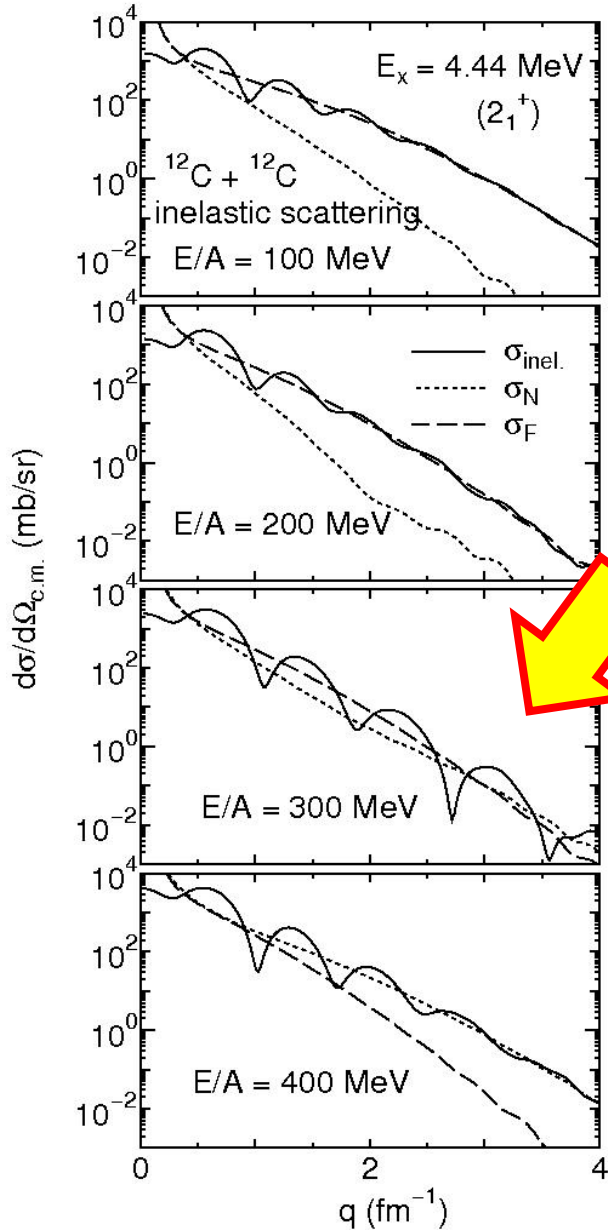


0_2^+

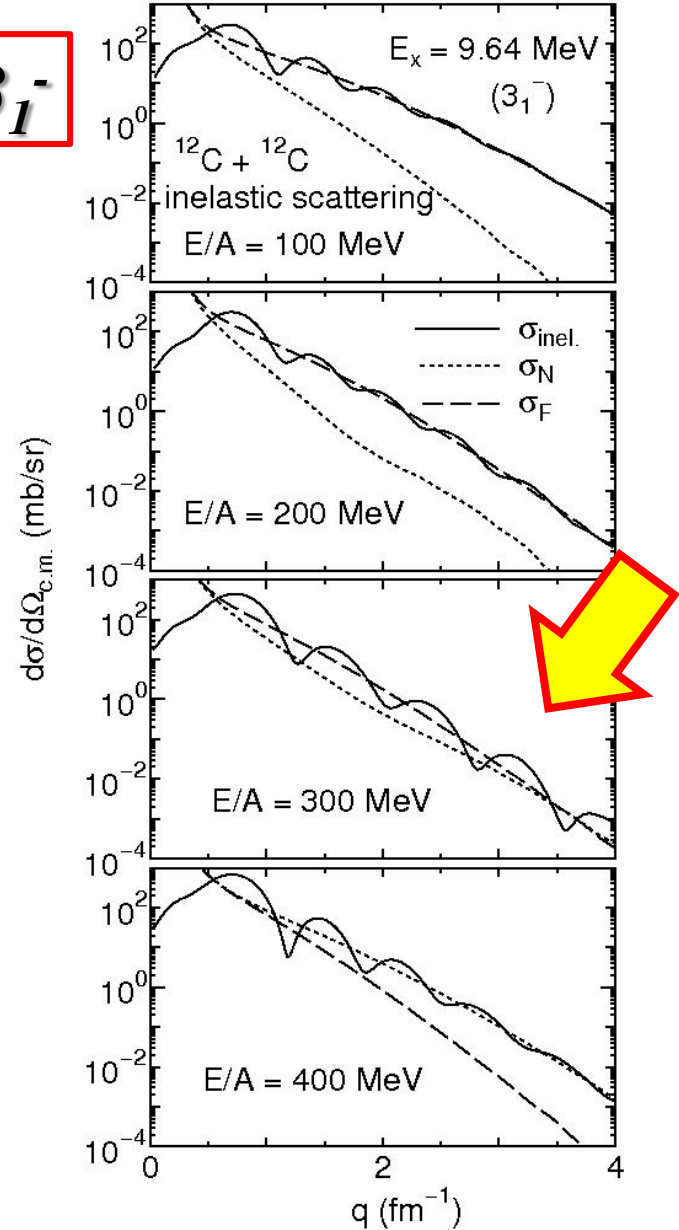


$^{12}\text{C} + ^{12}\text{C}$ inelastic scatterings at various energies

2_1^+



3_1^-



Summary

CEG07 folding model predicts the repulsive nuclear potential at high energy region ($E/A = 300 - 400$ MeV).

It is first survey that the repulsive potential for heavy-ion system is derived from the microscopic view point.

Property of nuclear repulsive potential

- The nearside becomes large and the farside becomes small around backward angles
by not Coulomb potential but nuclear potential.
- **The strong interference** appears at a certain energy by repulsive shift of nuclear potential in energy evolution.